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DEEP SCATTERING LAYERS IN THE GULF OF MEXICO

R. C. Thompson, J. W. Caruthers, and T. J. Bright

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13. ABSTRACT

The deep scattering layer (DSL) in the Gulf of Mexico has been studied, over a period of three years, utilizing a precision depth recorder operating at 12 kHz. The DSL appears to be divided into four main daytime layers. The west-central Gulf shows little deep layering. No definite correlation of DSL and physical parameters was arrived at. The DSL was not found to be seasonally variable. There were some indications that the DSL shoals to the north. Maximum rates of evening ascent of 3.4 fm/min (6.2 m/min) and morning descent of 5.9 fm/min (10.8 m/min) were determined. The length of time for ascent (2 hr) and descent 3 1/2 hr) are arrived at. Examples of evening ascent, morning descent and the dawn rise are presented. Response of the DSL to a total solar eclipse and cloud cover are discussed.

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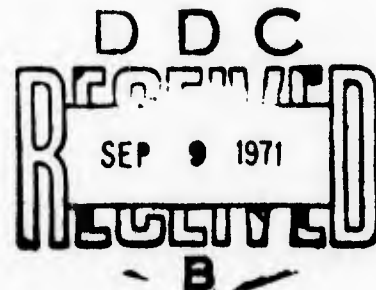College Station, Texas

DEEP SCATTERING LAYERS

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GULF OF MEXICO

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this document may be better
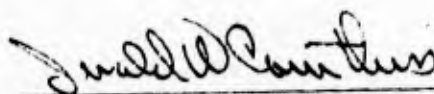studied on microfiche**

February 1971

Reference 71-5-T

PREFACE

The following study was carried out primarily by Ronald C. Thompson as his Master of Science research under the direction of the undersigned. The work was partially sponsored by the Office of Naval Research through Contract N00014-68-A-0308-0002 Project 700-14 for which Dr. Thomas J. Bright is the principal investigator.

This report reviews the existing data, presents the state of knowledge, and discusses certain specific features of deep scattering layers in the Gulf of Mexico.

Jerald W. Caruthers

ABSTRACT

The deep scattering layer (DSL) in the Gulf of Mexico has been studied, over a period of three years, utilizing a precision depth recorder operating at 12 kHz. The DSL appears to be divided into four main daytime layers. The west-central Gulf shows little deep layering. No definite correlation of DSL and physical parameters was arrived at. The DSL was not found to be seasonally variable. There were some indications that the DSL shoals to the north. Maximum rates of evening ascent of 3.4 fm/min (6.2 m/min) and morning descent of 5.9 fm/min (10.8 m/min) were determined. The length of time for ascent (2 hr) and descent (3 1/2 hr) are arrived at. Examples of evening ascent, morning descent and the dawn rise are presented. Response of the DSL to a total solar eclipse and cloud cover are discussed.

ACKNOWLEDGMENTS

The authors would like to express appreciation to Dr. Davis Fahlquist for reviewing this manuscript and suggesting improvements.

We wish to thank Dr. Guy Franceschini and Prof. John Cochrane for making available portions of their cruises, (70-A-4) and (70-A-9), respectively, for this research.

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INTRODUCTION

The objectives of this study are to present the general characteristics of the deep scattering layer (DSL), in the Gulf of Mexico, in reference to;

- the distribution of the DSL during the past three years,

- average and maximum rates of ascent and descent,

- correlation between DSL motion during the total solar eclipse in March, 1970, and the change in light intensity,

- correlation of DSL motion and cloudiness,

- correlation of DSL with various parameters, i.e., temperature, oxygen, salinity, and density (σ_t),

- observations of the dawn rise,[1] and

- occurrence of scattering layer groupings.

Data presented are derived from an examination of precision depth recorder (PDR) records obtained during the past three years operation of a 12 kHz shipboard fathometer. The records include several sets for which the quality of the display of the DSL was the primary objective. Included in this later set is a three day record of the DSL at one point. The test period included the total solar eclipse of 7 March 1970.

The citations on the following pages follow the style of the **Journal of the** Acoustical Society of America.

I. EARLY WORK

The deep scattering layer (DSL) is a widely distributed marine phenomenon[2-4] which most often appears as a midwater reflection on the trace of a precision depth recorder (PDR) when the recorder is used as part of an echo-sounding system. That this phenomenon is produced by the scattering of acoustic energy by marine organisms, which collect in horizontal layers, was first postulated by the University of California, Division of War Research, during the later part of World War II.[5]

The DSL ranges in depth from slightly below the surface down to at least 500 fm (914 m).[6] Most of these layers migrate toward the surface near dusk, and return to the depths near dawn. While this is usually true, not all of the layers migrate. Some layers remain at their midday depth, or slightly above their midday depth, throughout the diurnal cycle.[7-10]

Layering is, generally, laterally uniform during the daylight hours; it has been observed in the Pacific Ocean to be present during an entire days run of the ship.[3] Some shallow layering is observed at night; however, it is often obscurred by the outgoing ping of the PDR.[3]

The DSL is thought to be composed of many different organisms including: euphausids, copepods, myctophids, and siphonophores.[4, 7, 8, 11-17] These organisms are, in most cases, good sound scatterers, and are, possibly, the primary agent of marine

sound scattering.[18] There is, however, an apparent lack of correlation between the fishes and sound scattering in the upper 100 fm (183 m).[19]

Reflected sound from scattering layers is frequently associated with gas-bubbles. When gas-bubbles are insonified they are driven into oscillation and under certain physical conditions resonate. These conditions are determined by the relative impedances of the medium and the bubbles, the frequency of sound, and the shapes and sizes of the bubbles. Near resonance, the scattering cross sections of the gas-bubbles are much larger than their physical cross sections. The resonant frequencies of the gas-bubbles correspond to wavelengths much larger than the actual bubble diameters. Scattering layers have rather broad resonant peaks suggesting that they contain a distribution of gas-bubble scatterers of slightly different sizes.[10]

Resonant frequencies, generally, increase with increasing depth; this depth dependency is due primarily to changes in the physical characteristics of the gas-bubbles as the pressure (p) varies. If the gas-bubbles are spherical in shape, and free to compress or expand, then the resonant frequencies vary as $p^{1/2}$.[4,20] If they are oblate spheroids, the resonant frequencies vary as $p^{1/2}$, $p^{5/6}$ or p, depending upon whether the sizes and the shapes of the bubbles are constant, or the gas-bubbles are free to compress or to expand while maintaining the major diameter constant, respectively.[4,13,19]

It has been observed that as a layer undergoes diurnal migra-
tion its resonant frequency changes. Two cases of five-sixths
power and one of one-half power frequency dependences upon depth
have been reported for the western North Atlantic.[4,20]

DSL exist over most of our world's oceanic areas--the excep-
tions being the polar regions. There are, however, marked regional
variations:

- in the western Pacific layering has been observed at depths
  of 50 to 150 fm (91 to 274 m) and at 250 fm (457 m), the
  shallower layer being the most prominent;[21]

- one layer has been observed in the Bering Sea at
  200 fm (366 m);[7]

- off the coast of Southern California two layers have been
  detected, the shallow less prominent one at depths from
  85 to 135 fm (155 to 247 m), the deeper stronger one from
  135 to 200 fm (247 to 366 m);[7]

- on an earlier cruise off Southern California, a prominent
  layer was found at 150 fm (274 m);[2]

- in the Atlantic Ocean south of New England, two layers have
  been found, one at 164 fm (302 m) and the other at
  220 fm (402 m);[4]

- a prominent layer has been observed in the North Atlantic
  at 75 to 315 fm (137 to 576 m), with weaker layering from
  315 to 465 fm (576 to 850 m) and dominant scatterers
  within 55 fm (100 m) of the surface at night;[10]

- three layers have been detected in the eastern Gulf of
  Mexico, at 55 fm (100 m) with a thickness of 20 fm (37 m),
  at 75 fm (137 m) with a thickness of 10 fm (18 m), and
  at 136 fm (248 m);[22] and

- 35 mi (56 km) southwest of Key West, Florida, one layer
  was found at a depth of 200 fm (366 m) and with a thickness
  of 55 fm (100 m).[23]

In general, the ascent rates of the layers are not consistent
from one area to the next. Off Southern California, the maximum
observed ascent rate was 1 fm/min (1.8 m/min).[2] North of Puerto
Rico the maximum observed ascent rate was 2.5 fm/min (4.6 m/min).[24]
In the eastern Gulf of Mexico ascent rates as high as 6 fm/min
(11 m/min) have been observed.[22]

The scattering strength[25] is of the same order of magnitude
from place to place, but there is, however, some regional varia-
bility. The scattering strength in the western Pacific, as
examined with a precision depth recorder (PDR) system operating
at 12 kHz, varied from -106 to -61 db.[21] Off the east coast of
Nassau, the average scattering strength (averaged over the water
column) was found to vary from -82 to -53 db for a frequency
range of 1.6 to 20.0 kHz. This is, generally, about 10 db less
than that found off Bermuda, thus indicating a denser population
of organisms off Bermuda.[13] South of New England, the scattering
strength has been found to vary from -81 to -64 db for a frequency
range of 6 to 20.5 kHz.[4] In the eastern Gulf of Mexico the average

scattering strength has been found to vary from -69 to -51 db for
a frequency range of 2.5 to 20.0 kHz.[22]

The scattering strength, generally, decreases with increasing
depth except in the DSL, where it is from 5 to 15 db higher than
the local background.[26,27] The average scattering strength
appears to increase when the water column is insonified with higher
frequencies.[9] The scattering strength also appears to increase
with increasing latitude, possibly due to a slow northward shoaling
of the DSL.[4]

The majority of the data used in this paper are derived from
precision depth recorder (PDR) records. Only a relatively few
PDR records obtained in the past provide good data. Most cruises
utilize the PDR as a means to delineate the bottom profile; the
PDR is not adjusted to enhance midwater layering, such as the DSL.
It is possible, through proper adjustments of the PDR gains, to
produce a good trace of the DSL. But, still, the PDR is limited
in what it detects as it operates at a single frequency; one layer
is usually represented by a PDR trace which is considerably darker
than those of the other layers at the same location. This darker
layer may represent a layer of organisms that are resonant at or
near the operating frequency of the PDR, while the other, apparently
weaker, layers may be resonant at other frequencies. Thus, their
lightness does not necessarily mean that they are not dense and
well defined.

For the degree of darkening of the PDR trace that is observed,

it is not necessary that there be a high concentration of
scatterers present. It is possible to get darkening of the PDR
trace that is representative of a typical DSL if there are as few
as 0.0006 scatterers/fm^3 (0.0001 scatterers/m^3) present.[28]
The actual concentrations, as observed in situ, are substantially
larger. Off Southern California, a population density of
0.22 scatterers/fm^3 (0.036 scatterers/m^3),[7] and off the northern
coast of Puerto Rico 0.50 scatterers/fm^3 (0.082 scatterers/m^3),[24]
have been observed, while in the eastern Gulf of Mexico the density
has been found to be 0.12 scatterers/fm^3 (0.02 scatterers/m^3).[29]

The DSL of other oceanic regions is quite thoroughly studied;
there is, however, a lack of information concerning the DSL in
the Gulf of Mexico.[30] This dearth of knowledge, compounded by
the fact that in the Gulf of Mexico the DSL is quite pronounced
and interesting, has prompted this investigation.

II. OBSERVATIONS OF GENERAL DSL CHARACTERISTICS

A. Past Data

A summary of the areas of DSL occurrence in the Gulf, as obtained from a review of 7,000 hrs of PDR records taken aboard the R/V Alaminos using a 12 kHz echo-sounding system, is presented in Fig. 1. The PDR records were examined and data extracted consisted of depth, thickness, number of layers, time, place, extent and rates of motion of the DSL. The high concentration of points extending from off the Texas coast to the Yucatan strait is undoubtedly due to the high frequency of observations made in this area, rather than any real regional variability of the DSL. A review of the data reveals the following points concerning the DSL.

There appear to be four main, daytime, layering regimes in the Gulf: surface layers to a depth of 30 fm (55 m); relatively thin layers from 31 to 100 fm (55 to 183 m); another series of thin layers from 101 to 170 fm (185 to 261 m); and a thick layer from about 171 to 260 fm (263 to 476 m) (See Fig. 2). These layers were not present at all locations; usually the deeper layer was missing, and sometimes no layering could be found in the 101 to 170 fm (185 to 261 m) depth. No layering was found below 270 fm (494 m). The central and extreme southwestern Gulf appear to be areas of high DSL occurrence (the data for the southwestern Gulf were based on only a few data points). The

Numbers are the number of DSL observations in a two degree square, centered at the number.
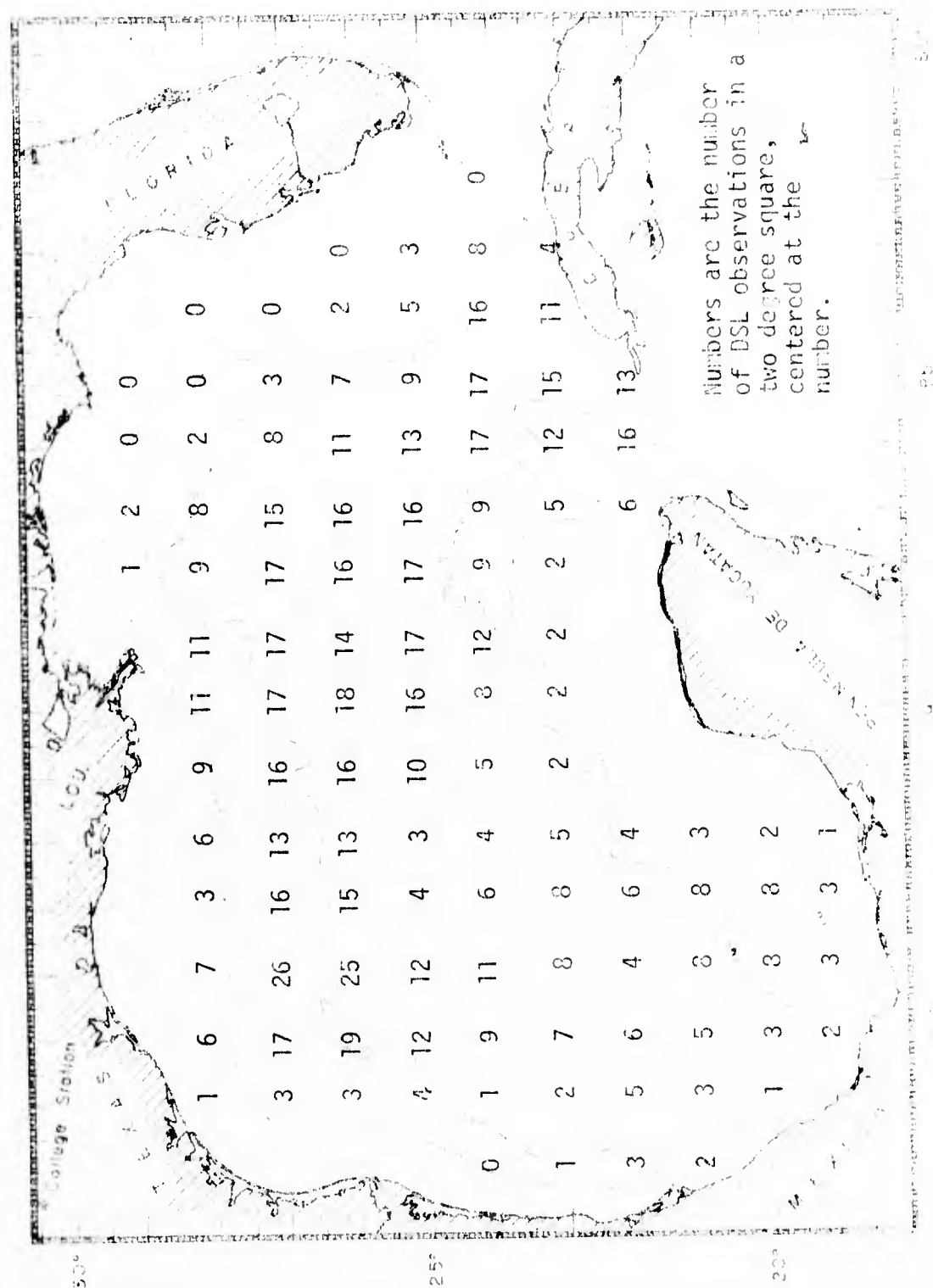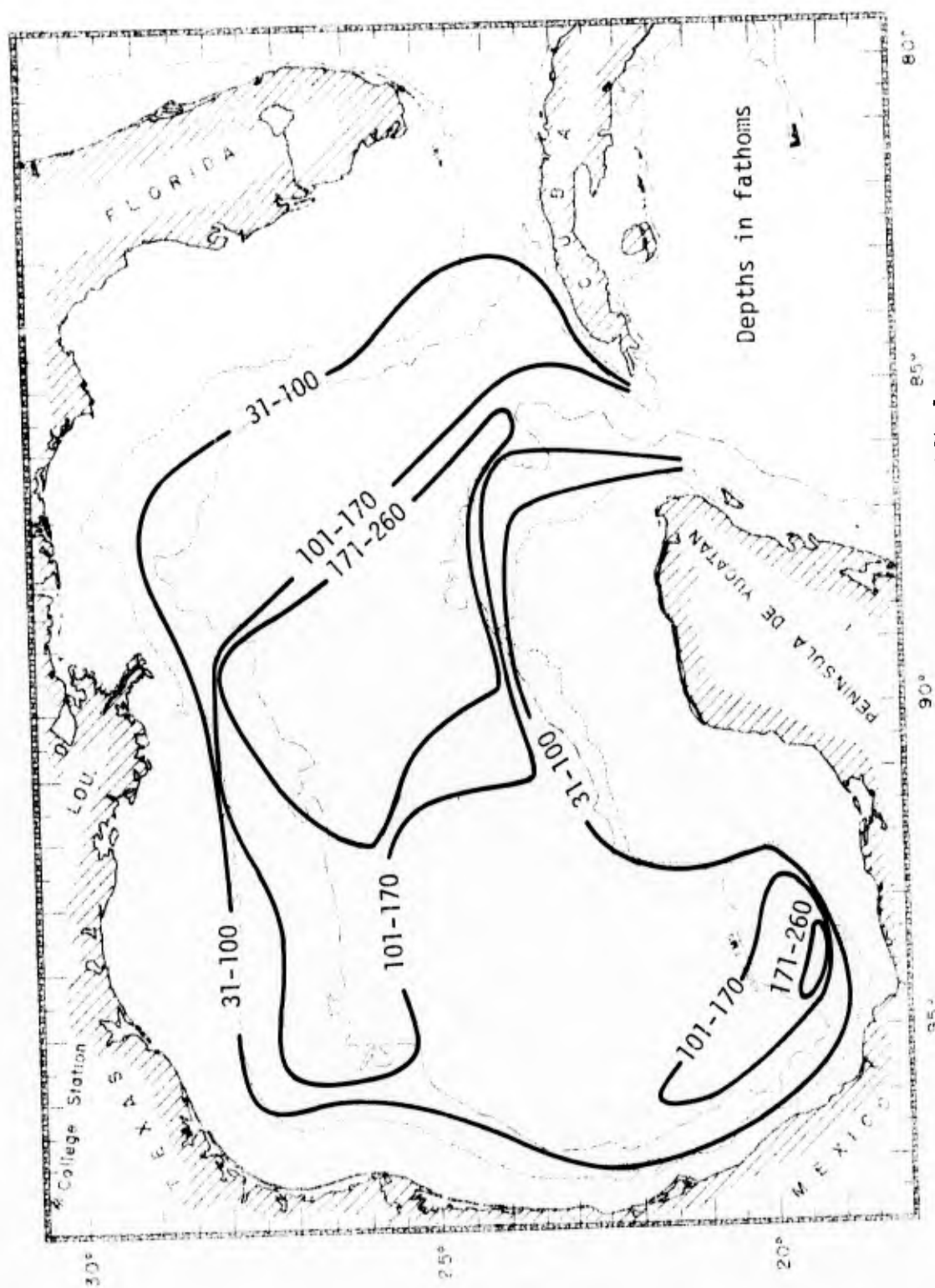
Fig. 1 - DSL observations during past three years.

Fig. 2 - Areal extent of deepest DSL layers.

central portion of the western Gulf seems to have shallow layer-
ing only.

The individual layers, of the DSL, are often found to be
patchy. This patchiness makes it difficult to follow any one
layer over any appreciable horizontal distance. It was sometimes
possible to follow a DSL complex (i.e., a number of layers, not,
however, usually the same layers) through a number of diurnal
cycles, both when on station and when underway.

An attempt was made to distinguish between summer and winter
DSL layering (See Figs. 3(a) and 3(b)). Comparison of the two
figures indicates a separation of the DSL into two regimes: the
winter, with most occurrences in the eastern Gulf, and the summer,
with most occurrences in the western Gulf. This apparent separa-
tion is not ascribed to seasonal differences but rather to the
cruise pattern for the past three years (See Fig. 4). A seasonal
variation is not, however, precluded. It may be necessary to
examine the DSL, in a specified area of the Gulf, periodically over
an extended period of time before a long term variation becomes
evident.

Attempts were made to correlate the Gulf-wide distribution
of the DSL with such parameters as the temperature, oxygen,
salinity and density (σ_t);[31] the data were such that no definite
correlation could be established (See Figs. 5(a) through 5(i)).
There does, however, appear to be a general northward shoaling
of the DSL as is evidenced by data presented in Figs. 5(b)

Summer 3-21 to 9-22

Numbers are the number of DSL observations in a two degree square centered at the number.
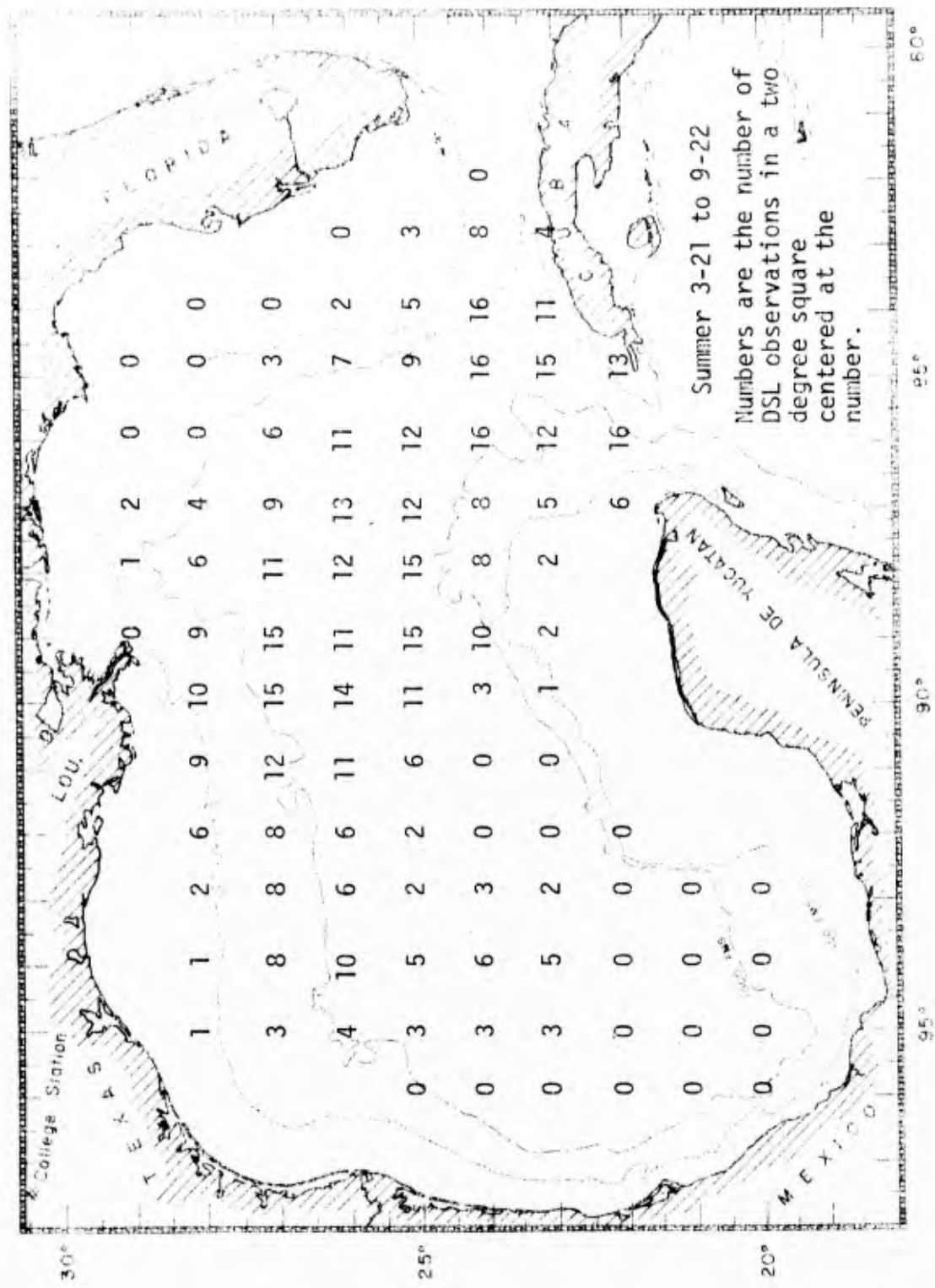
Fig. 3(a) - Summer DSL observations.

13
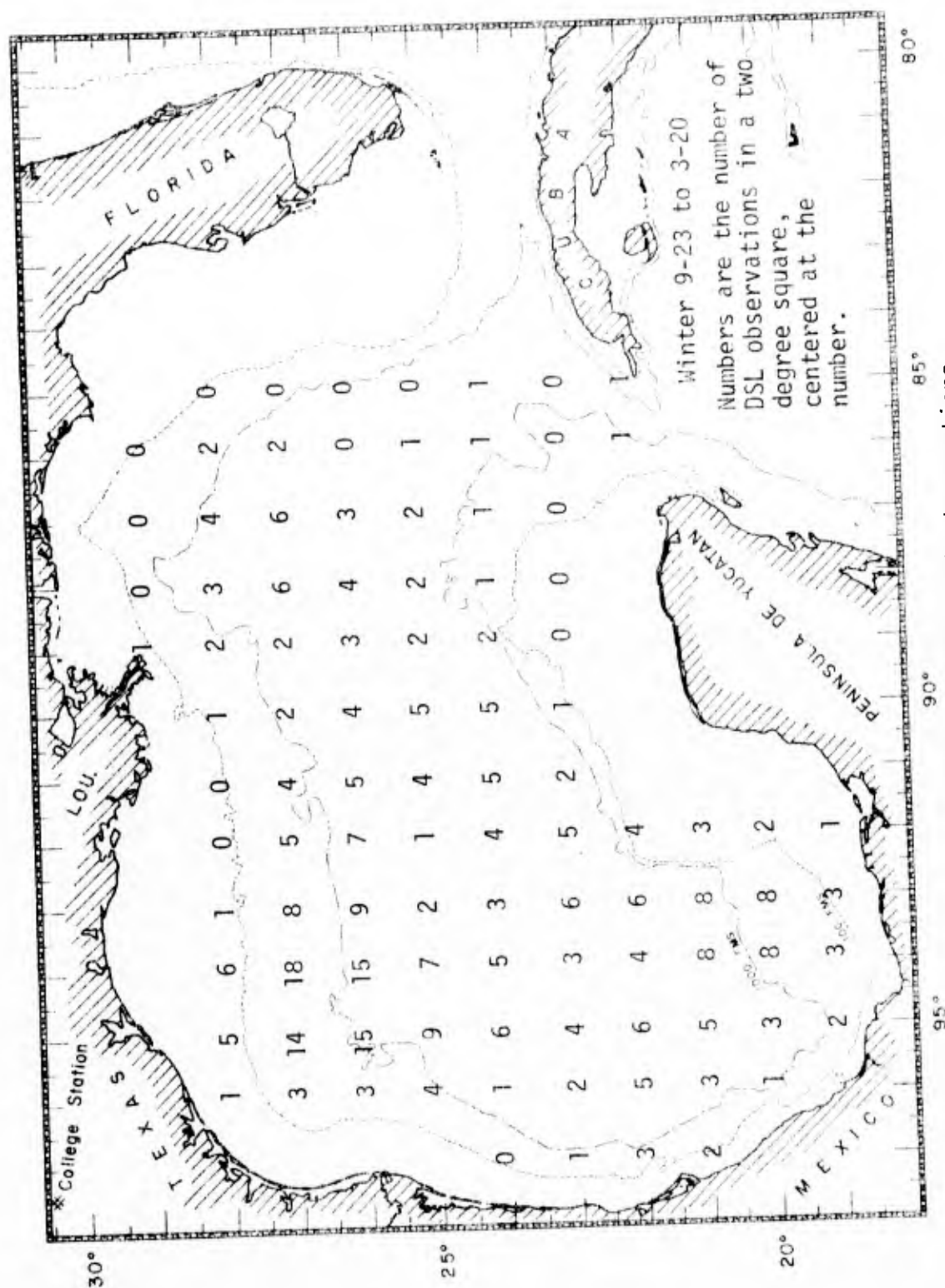
Fig. 3(b) - Winter DSL observations

Fig. 4 - Composite of cruise tracks for past three years.
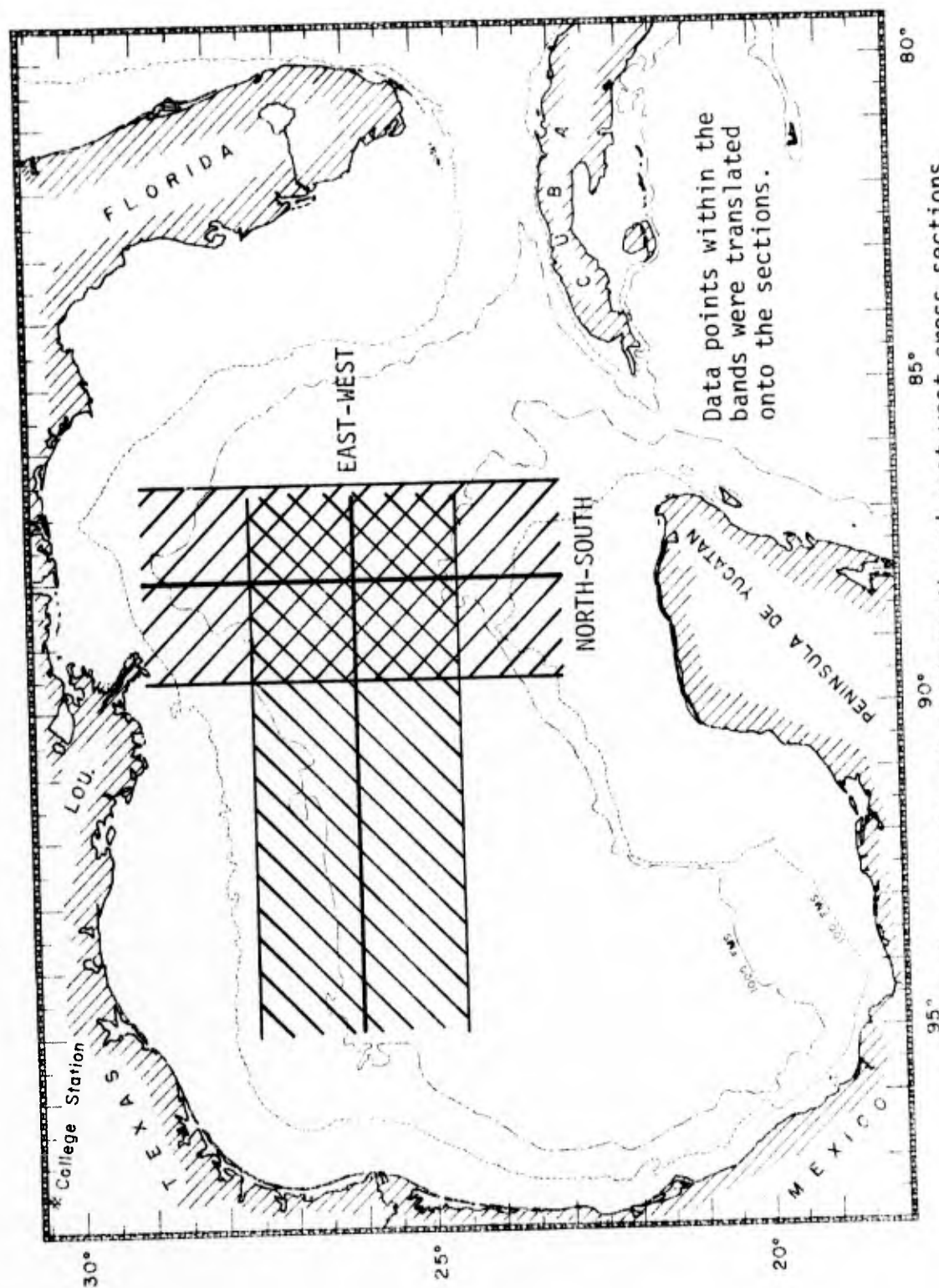
Fig. 5(a) - Location of north-south and east-west cross sections
for figures 5(b) through 5(i).

Fig. 5(b) - DSL and general north-south temperature profile, summer.

Fig. 5(c) - DSL and general north-south salinity profile, summer.

88° WEST

*CONTOUR SCALE

LATITUDE

DEPTH (M)

DEPTH (FM)

SALINITY (°/₀₀)*

Fig. 5(d) - DSL and general north-south oxygen profile, summer.

Fig. 5(e) - DSL and general north-south σ_t profile, summer.

Fig. 5(f) - DSL and general east-west temperature profile, summer.

Fig. 5(g) - DSL and general east-west salinity profile, summer.

Fig. 5(h) - DSL and general east-west oxygen profile, summer.
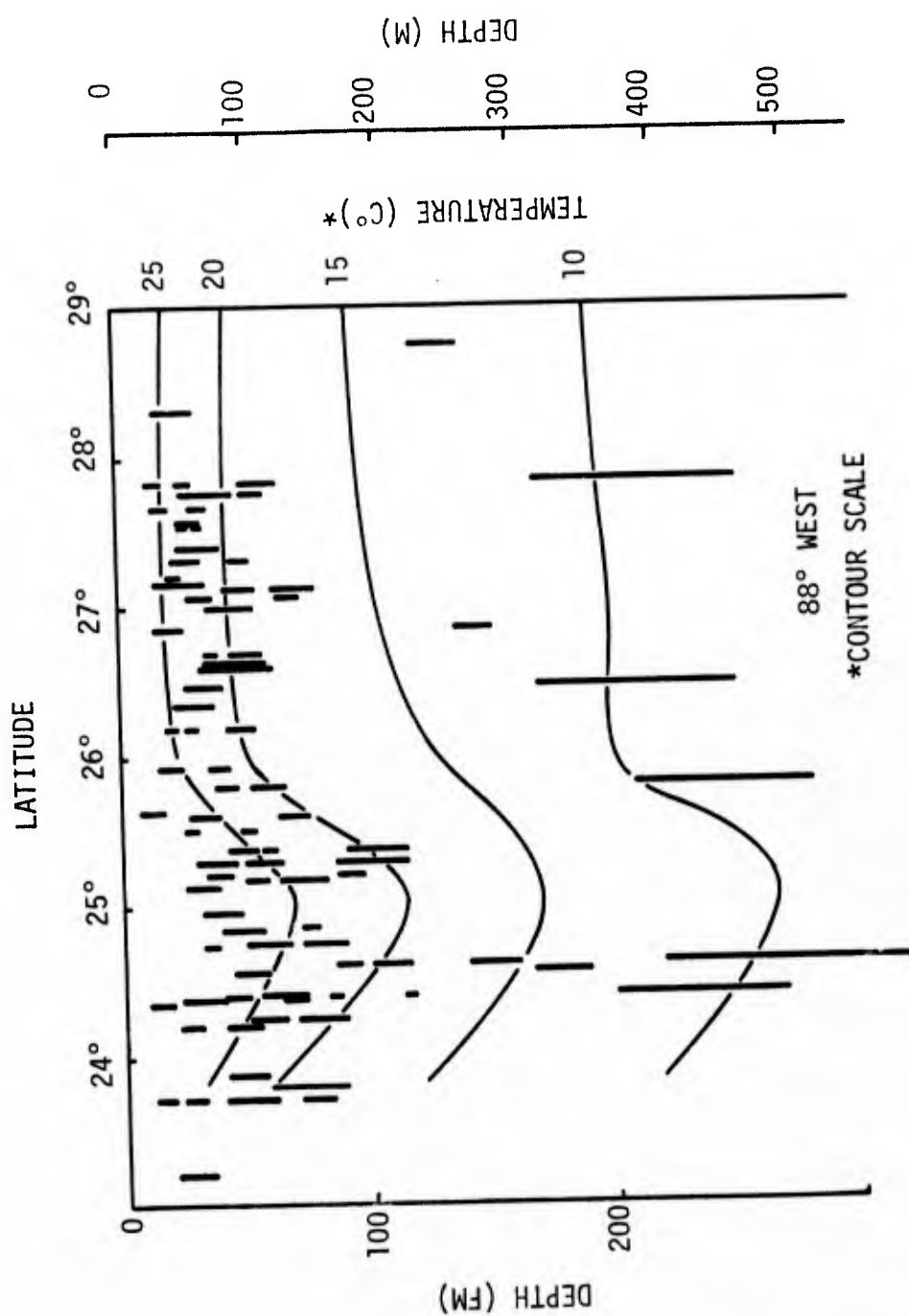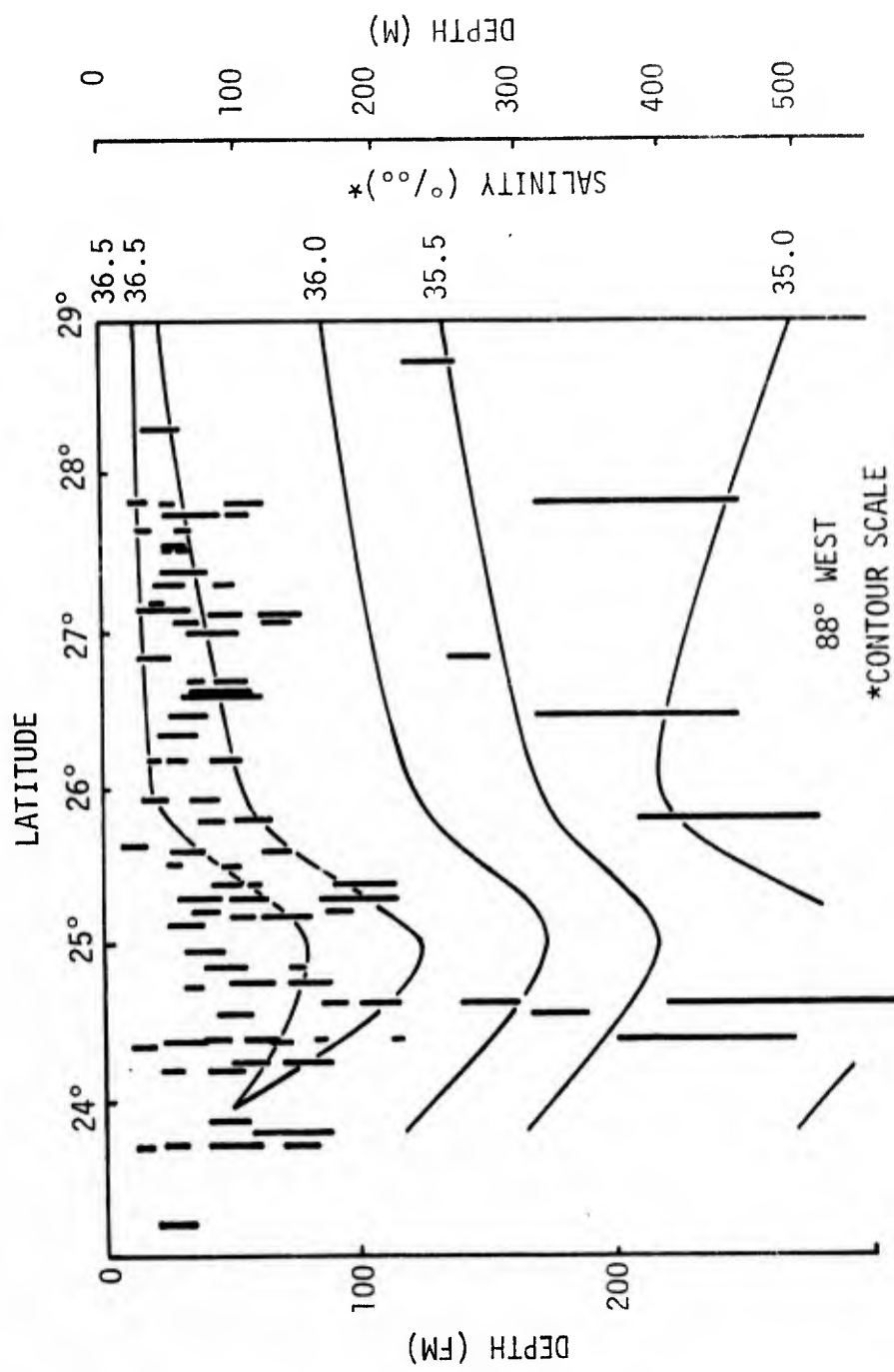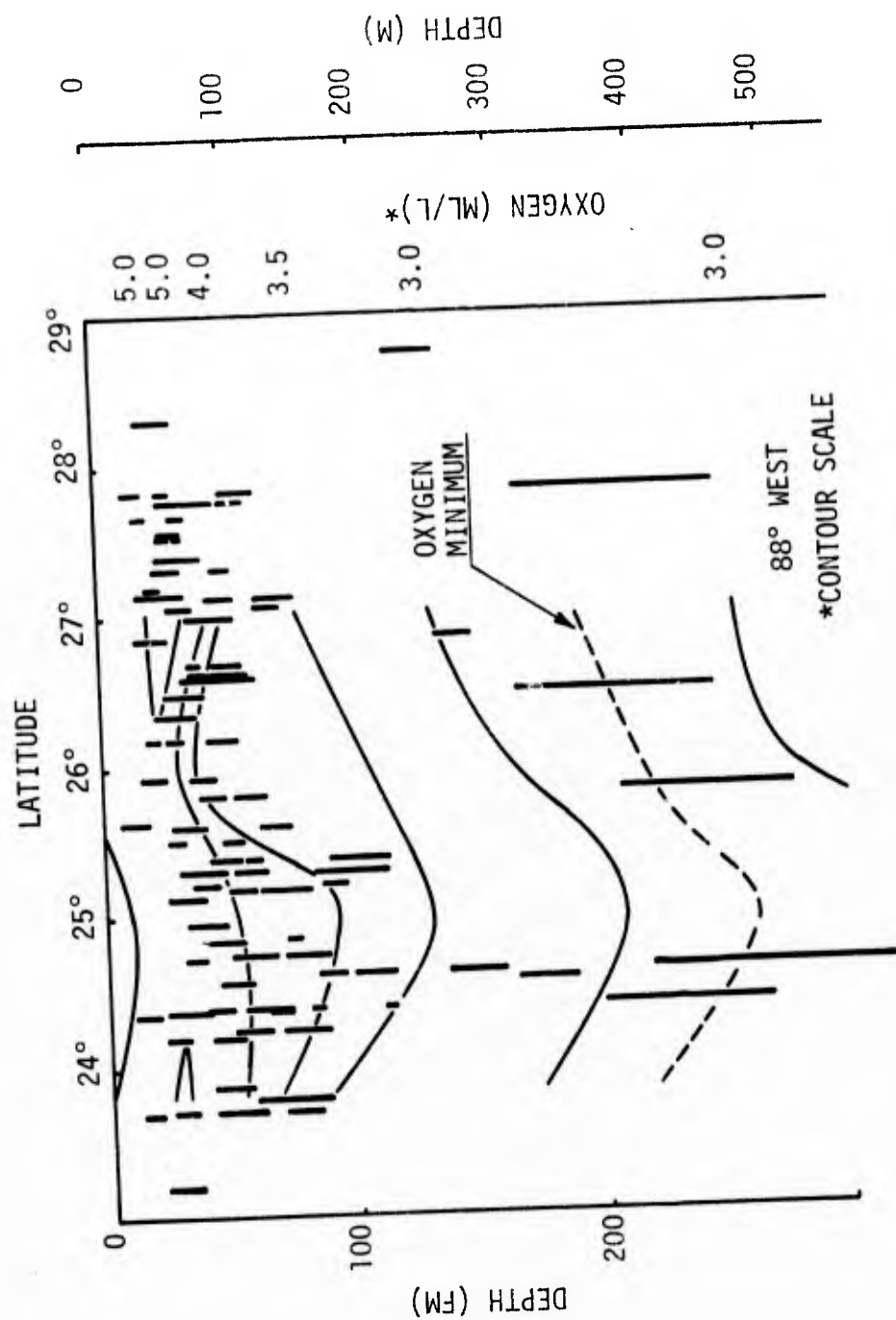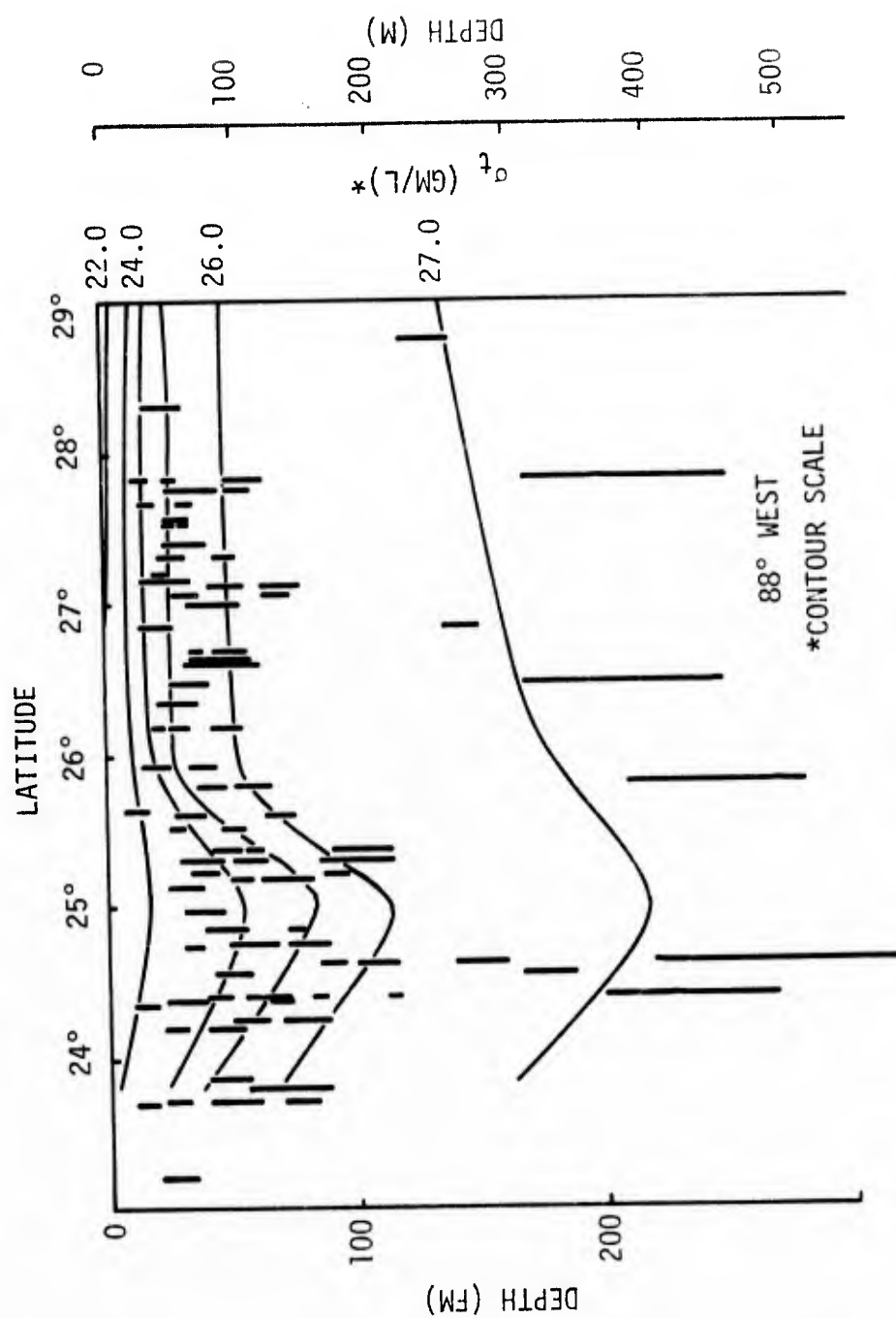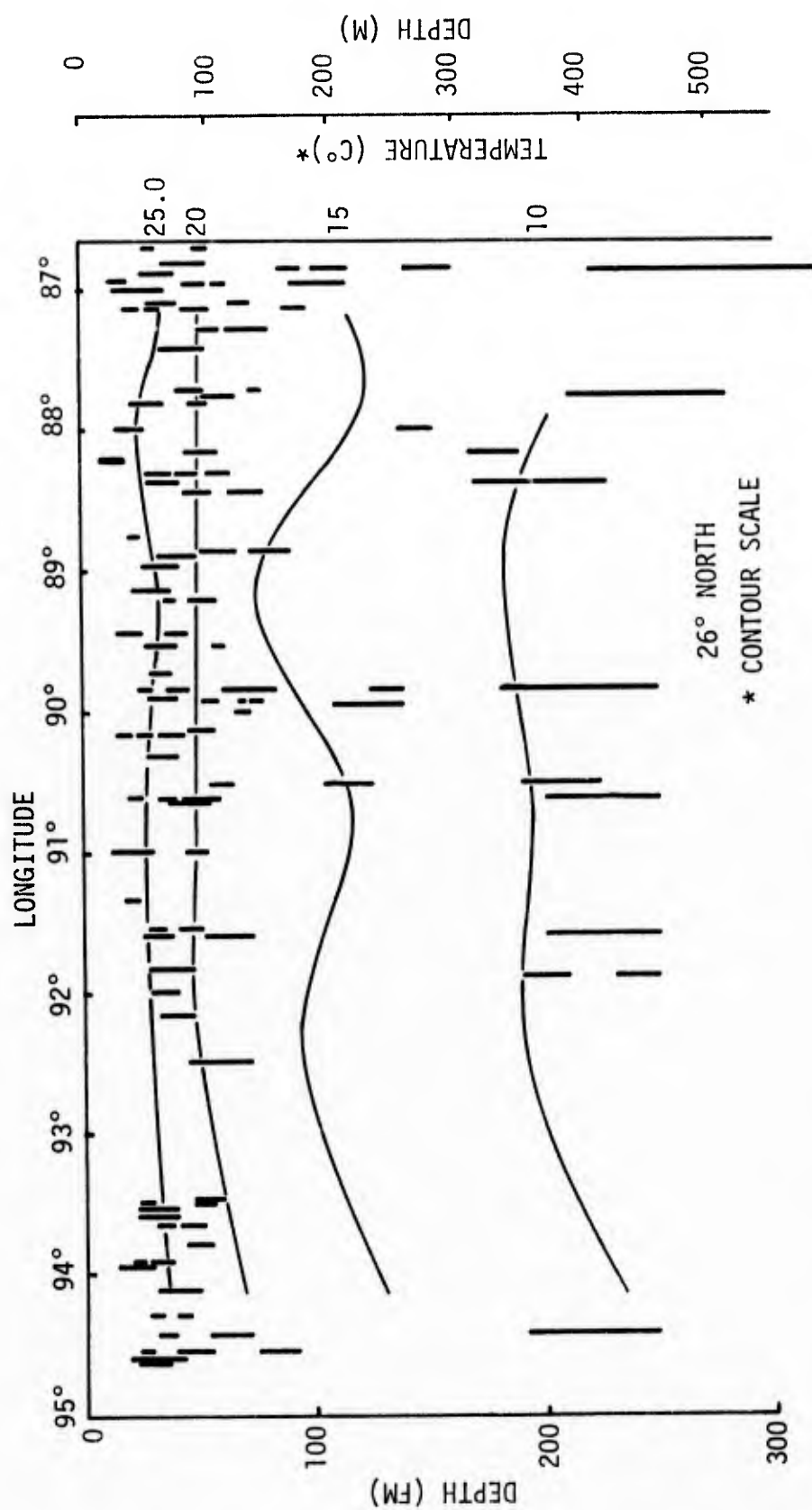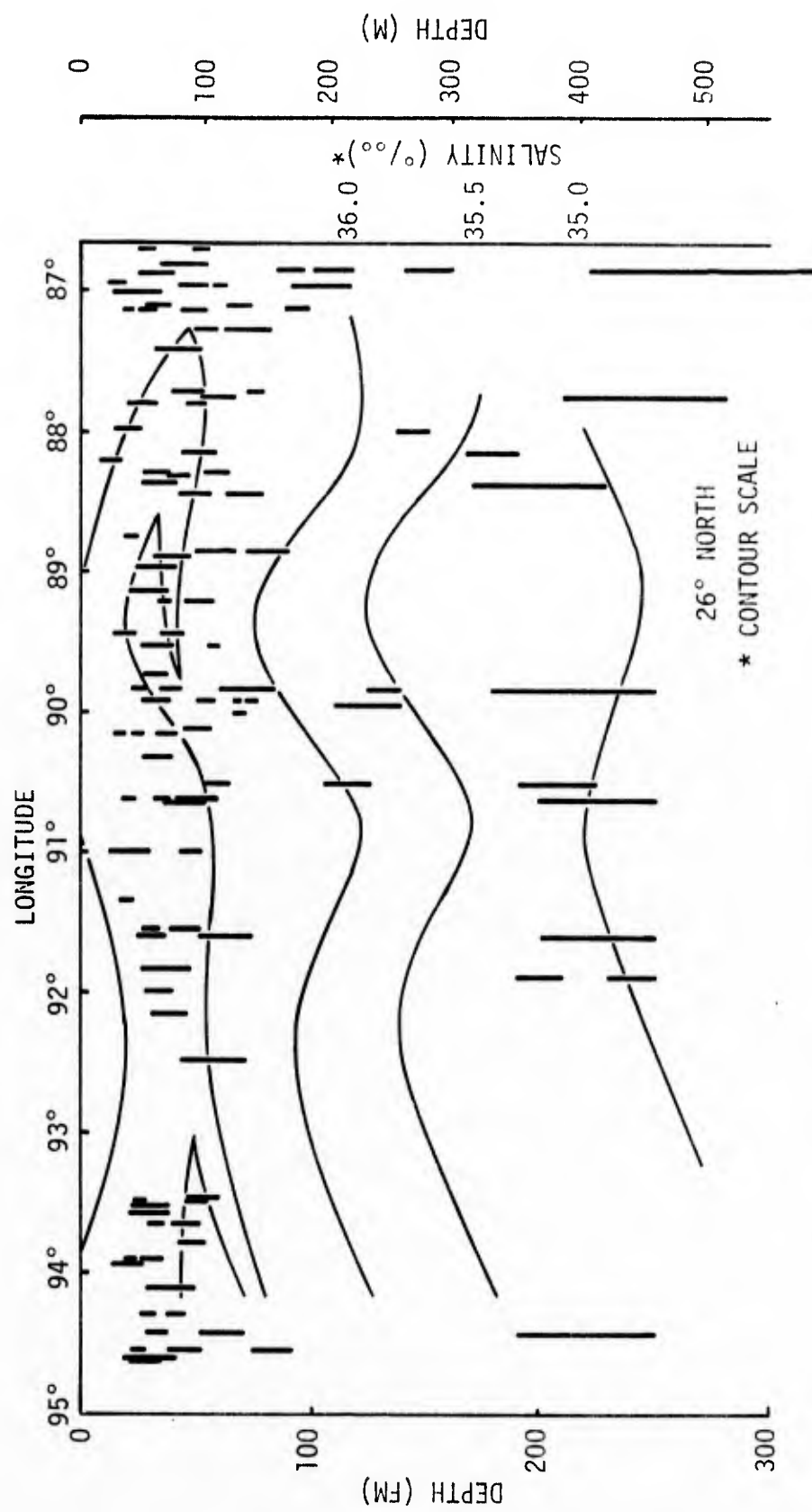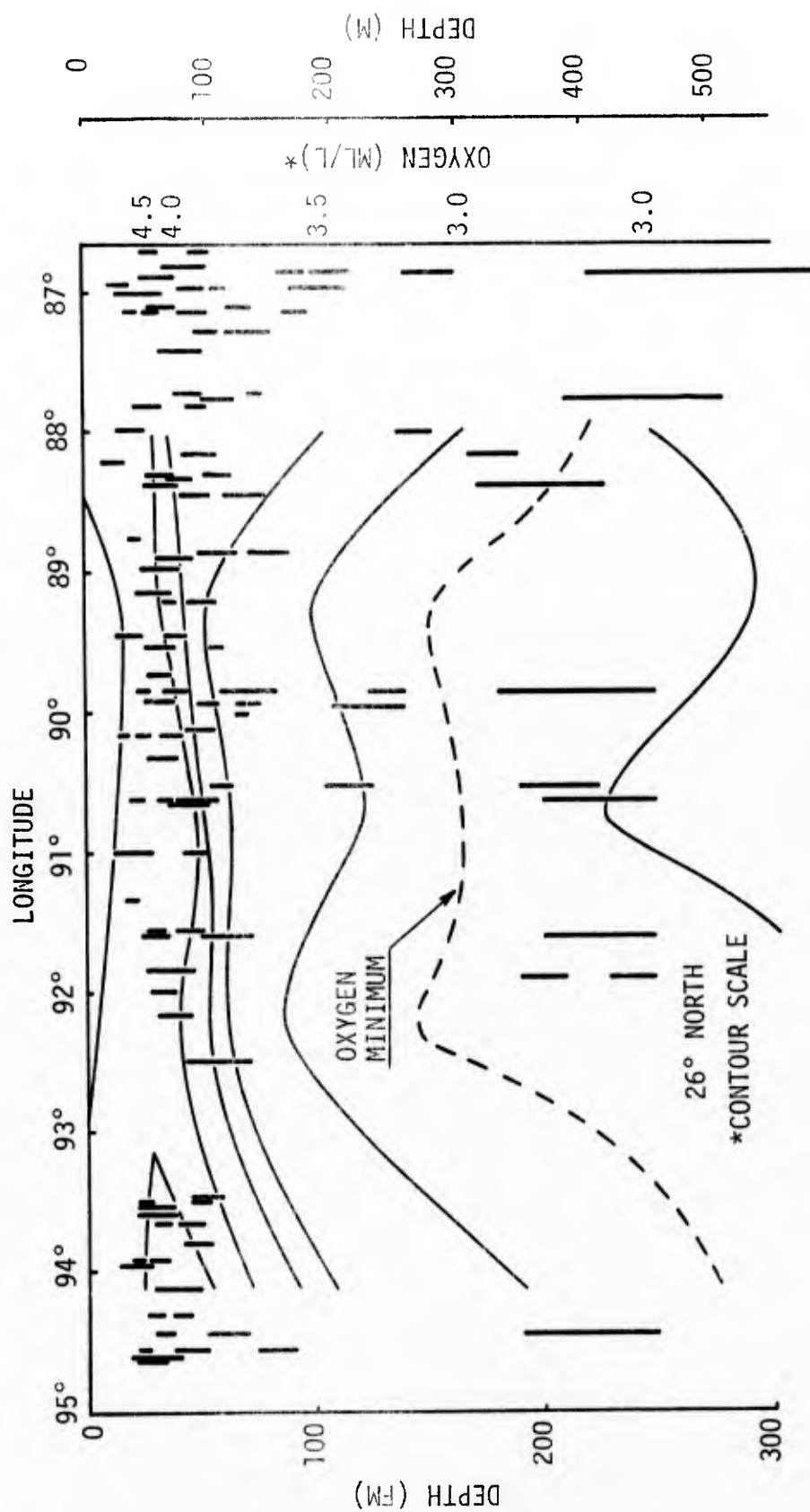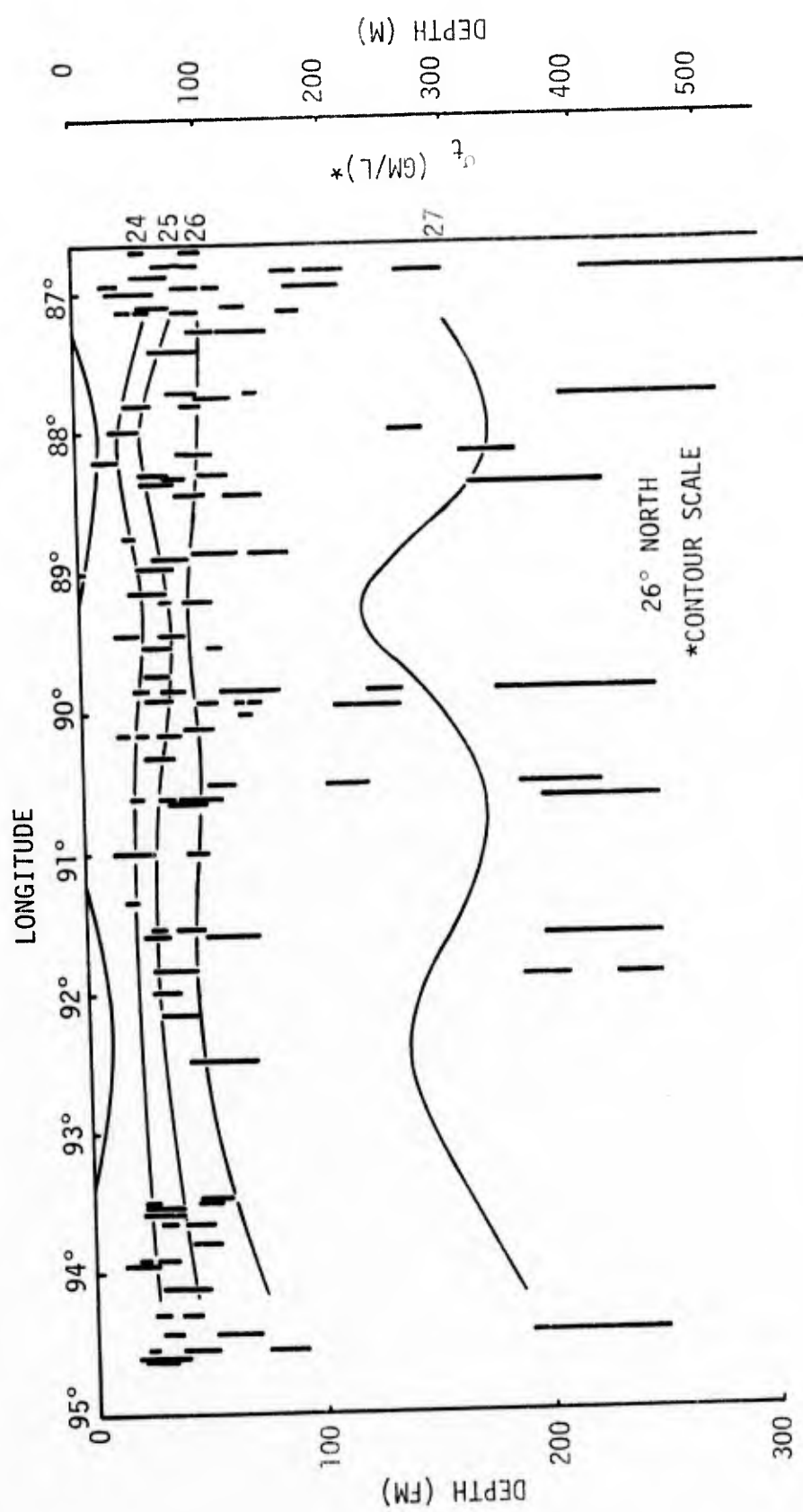
Fig. 5(i) - DSL and general east-west σ_t profile, summer.

through 5(e). The shallower (less than 100 fm (183 m)) DSL appear
to conform to portions of the water column that are coexistent
with rapid vertical change of such parameters as temperature,
salinity, oxygen and σ_t. There is less pronounced correlation of
the DSL with these parameters as shown on the east-west sections
(See Figs. 5(f) through 5(i)), as compared with the correlated
north-south sections (See Figs. 5(b) through 5(e)). This is
possibly because there is a greater degree of variability in the
east-west direction than in the north-south direction in the Gulf.
The only conclusion that can be drawn, based upon the existing
data, is that there is no definite correlation between the various
physical parameters and the distribution of the DSL in the Gulf of
Mexico. This conclusion will, it is expected, be altered as more,
and better, data become available in the future.

B. Recent Data

On two recent cruises of the R/V Alaminos (70-A-4 and
70-A-9), observers were on board with the primary task of improving
the DSL data (this was done by close control of the PDR system).
A large volume of precision depth recorder tracings as well as some
simultaneous magnetic tape recordings of the PDR signal were
obtained. The location of specific DSL observations are presented
in Fig. 6.

Data from these cruises were used in attempts to arrive at
correlated DSL motion with temperature and temperature gradient.
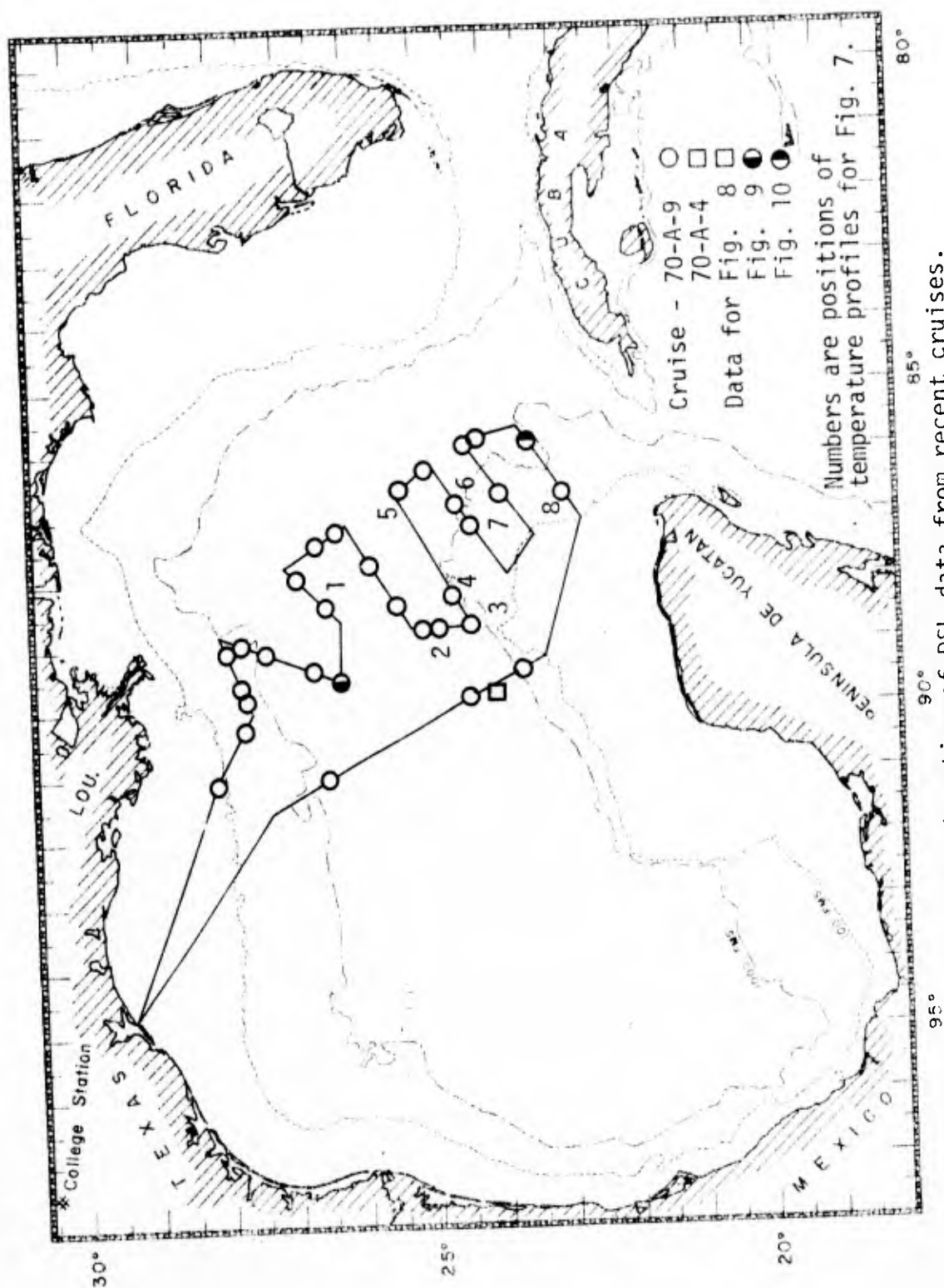
Fig. 6 - Location of DSL data from recent cruises.

There is the possibility that some degree of correlation exists
between the vertical temperature structure and the depth of the
DSL (See Fig. 7); however, no consistent set of data indicating
such could be concluded.

Through the continuous monitoring of the PDR gains, the quality
of the data was a marked improvement over that of past data, and,
in general, the data confirmed the conclusions drawn from past
data. Specific features, found in both recent and past data, are
discussed in the following sections.

Fig. 7 - Selected temperature profiles from cruise 70-A-9 showing prominent DSL.

For clarity the profiles are displaced to the right; sea surface temperatures are given on each profile.

*See Fig. 6 for location of profiles.

III. DISCUSSION OF SPECIFIC DSL BEHAVIOR

A. Multiple Layering

Multiple layering is often observed in the Gulf. On a cruise in March, 1970, while maintaining station, six distinct layers were observed at depths to 225 fm (412 m) (See Fig. 8), these layers were stable over the observation period of three days. Also shown in the figure are some volume scattering measurements taken utilizing · the PDR system. The outgoing and returning pings were recorded on magnetic tape. The relative values of the intensity, as shown on the figure, are from averages of several pings taken from the magnetic tapes. Table I summar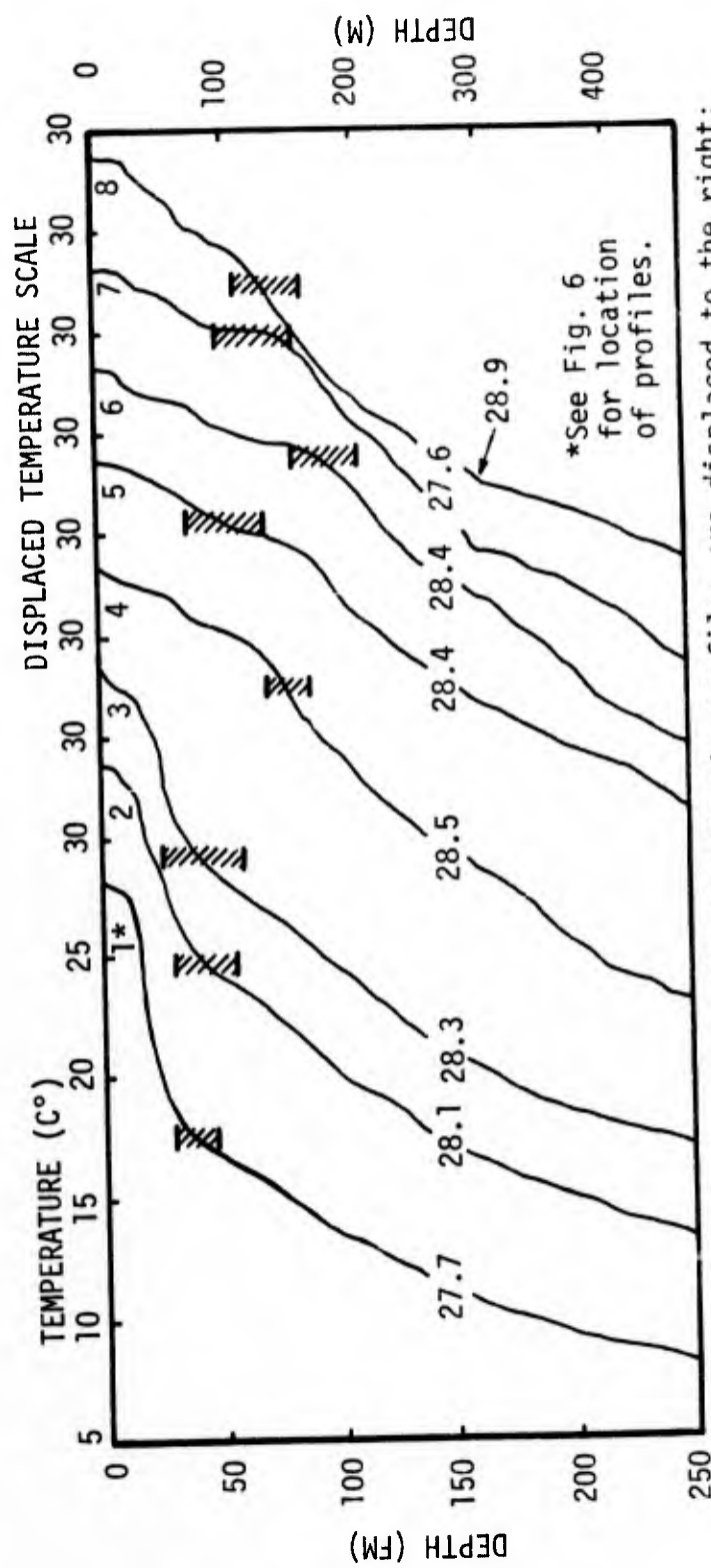izes the layering as it was observed during the test period. The layers were continuous from morning to evening of the same day, and from one day to the next they appeared to be continuous.

On a subsequent cruise in June, 1970, multiple layering was observed on a number of occasions. Fig. 9 is a photograph of a PDR tracing showing an observation of five layers in the central Gulf; these layers range in depth to 180 fm (329 m). In the southeastern Gulf, on the same cruise, seven layers were observed (See Fig. 10) ranging in depth to 240 fm (431 m). As can be seen on the figure the shallow layers appear to be horizontally patchy.
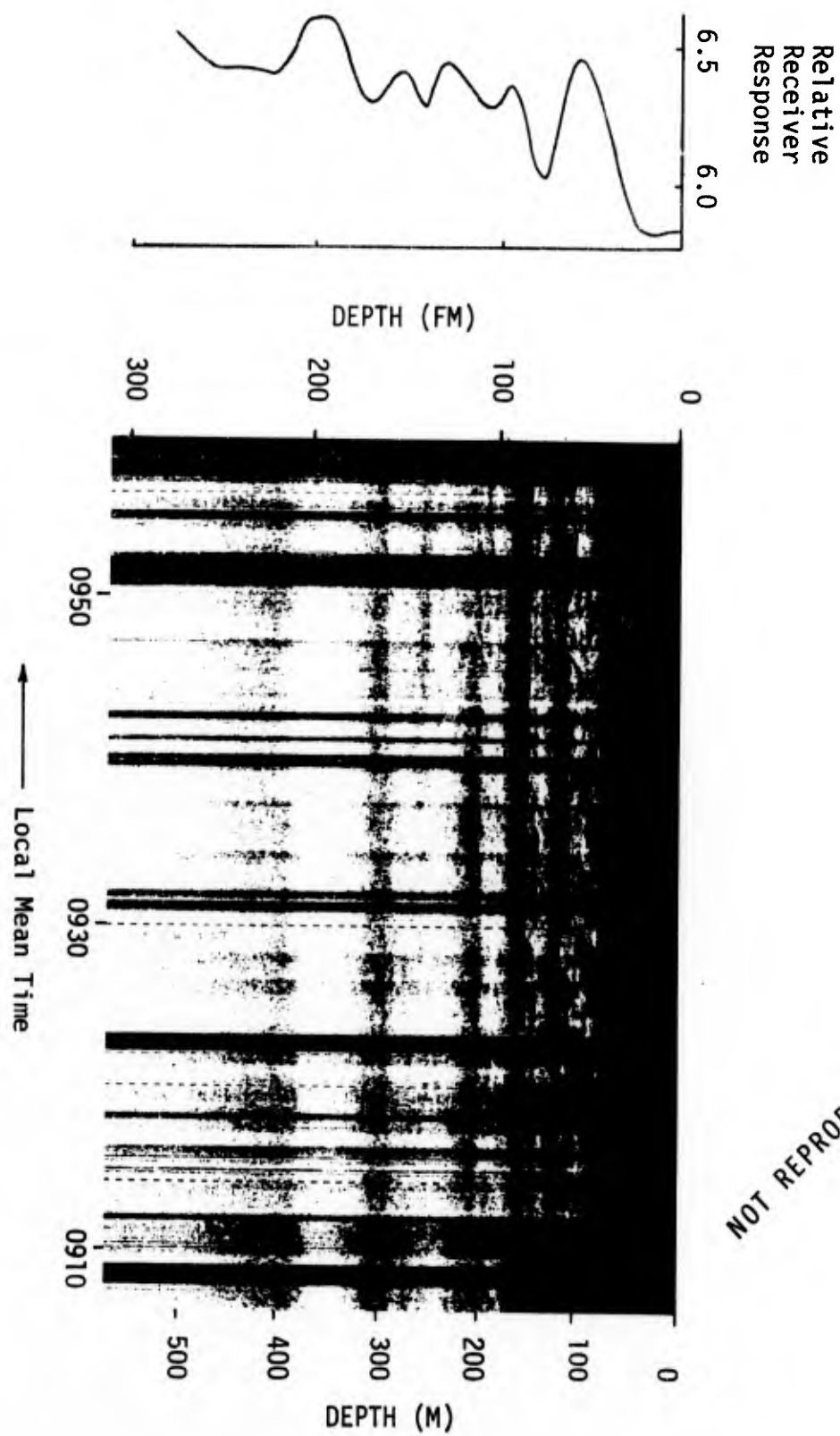
Fig. 8 - Photograph of PDR trace for the morning of the total solar eclipse, relative receiver response is also shown.

Layer Number	Afternoon[a] 3/6/70	Morning 3/7/70	Afternoon 3/7/70	Morning 3/8/70	Afternoon 3/8/70
1				35 Ms	30 Ms
2		65 Hm	b	70 Mm	
3	90 Ls[c]	85 Hs	85 Ms	85 Mm	85 Ms
4		110 Hw		120 Mw	120 Mw
5		135 Hw			
6		160 Hw	150 Mw	160 Mw	160 Mw
7		220 Hw	220 Mw		210 Mw

[a]No specific times are assigned here since the layering was generally constant during these periods.

[b]Layer broke up into individual scatterers.

[c]Capital letters refer to relative gain settings (H, high; M, moderate); lower case letters refer to relative darkening of PDR record (s, strong; m, medium; w, weak).

TABLE I.   Depth (in fathoms) of observed layers

Fig. 9 - Photograph of PDR trace showing multiple layering.

31

Fig. 10 - Photograph of PDR trace showing multiple layering in the southeastern Gulf.

DEPTH (M)

Local Mean Time

DEPTH (FM)

NOT REPRODUCIBLE

32

B. Diurnal Migration

Fig. 11 is a composite diagram of individual evening ascents
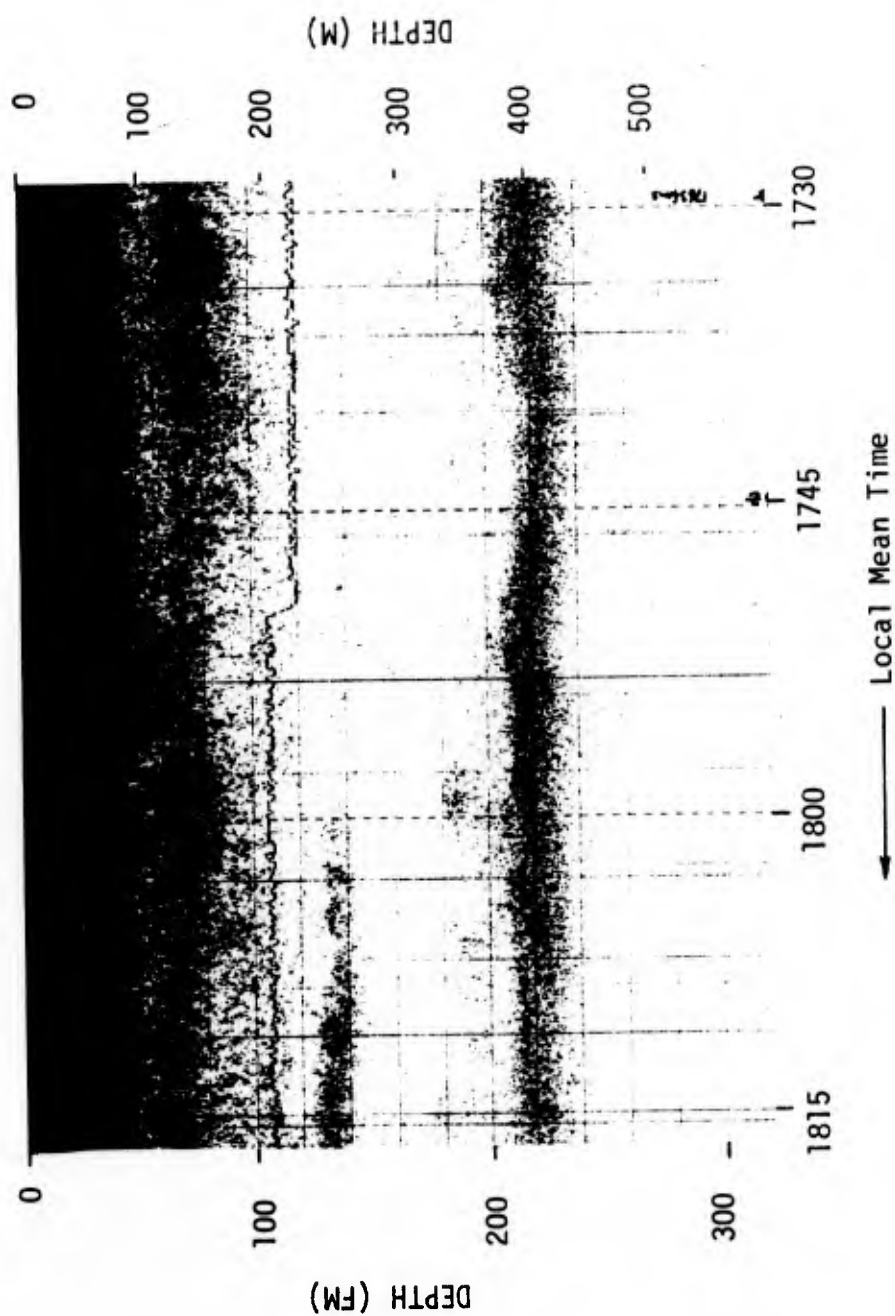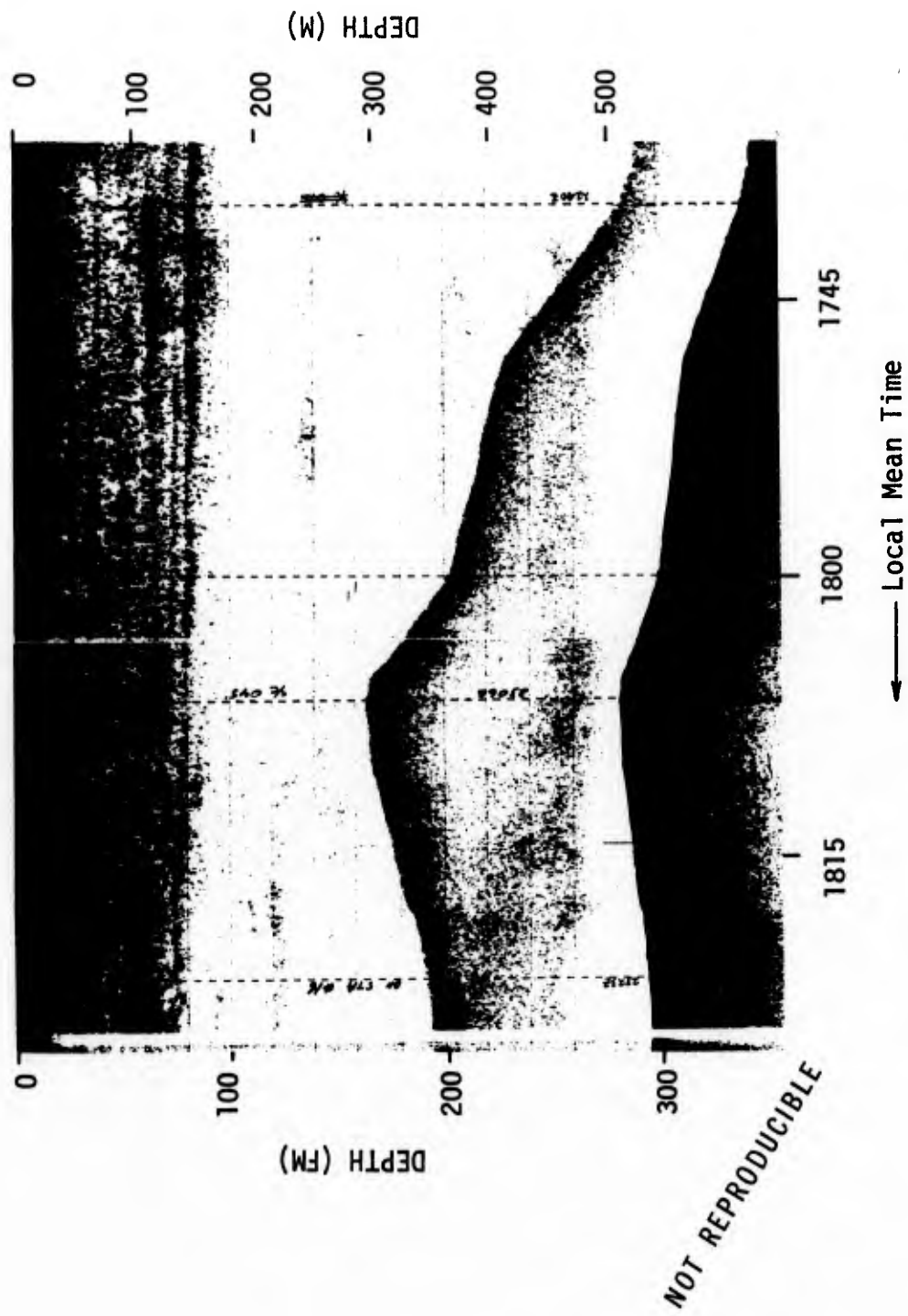and morning descents; collectively, representing typical evening
and morning migrations. There are a number of migratory regimes:
the near surface, which undergoes little or no vertical migration;
the intermediate, which descends to depths as great as 125 fm.
(229 m); the deep, which descends to depths of the order of 225 fm
(412 m); and, possibly, deeper layering.

As the layers descend they separate into other layers,
usually undergoing further splitting prior to approaching a stable
depth; ascent is similar to, but opposite, descent. While the
downward migration of the deeper layers seldom takes longer than
two hours, the upward migration takes as long as 3 1/2 hrs to
complete--depending upon the initial depth of the layer; the
deeper the layer the longer it takes to reach its near surface
nighttime level.

The first portion of the evening ascent and the last portion
of the morning descent are slow (less than a half a fathom a
minute (less than a meter a minute)). During the last hour, the
motion is fairly rapid (about 1.3 fm/min (2.4 m/min) for the
ascent and about 1.8 fm/min (3.3 m/min) for the descent--the
maximum rates being 3.4 and 5.9 fm/min (6.2 and 10.8 m/min),
respectively). The layers start their rapid descent about an hour
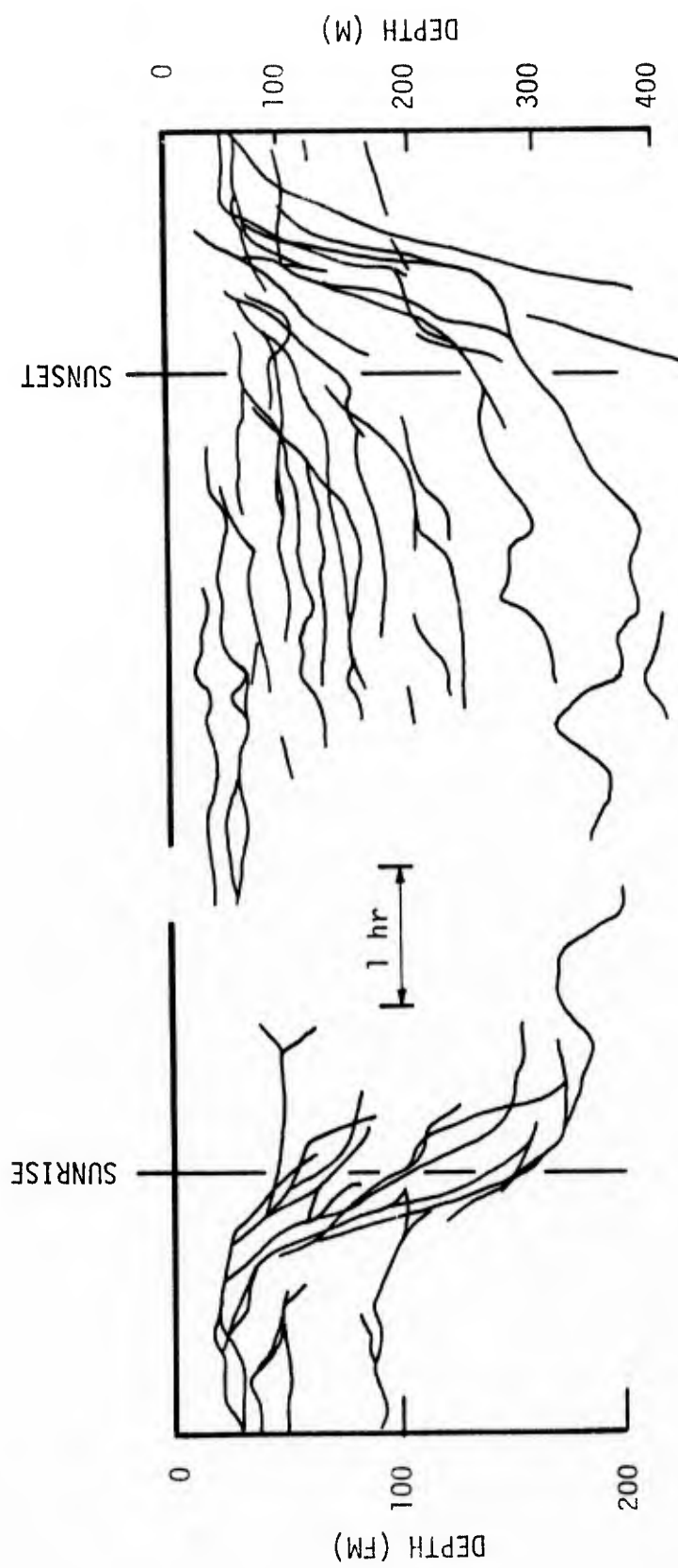prior to sunrise; the rapid portion of the evening ascent starts

Fig. 11 - Composite morning descent and evening ascent.

about the same time interval prior to sunset. It is often difficult, with certainty, to follow the DSL throughout its period of vertical migration.

An example of the evening ascent is shown in Fig. 12. Not all of the layers start their evening rise or arrive at their shallowest depth at the same time. Prior to the beginning of the rise, at least three layers were present 60 (110), 105 (192) and 200 (366) fm (m) deep (See Fig. 13). The layer at a depth of 200 fm (366 m) could be followed into the rise, and seen to separate into two layers during the early portion of the rise.

Layers can often be seen to form during the descent (See Figs. 14 and 15). Often, while the layers are preparing to descend, they will first rise toward the surface; this "dawn rise" is discussed in a later section. Two layers are seen to descend; the deeper layer started down at about 0500 h LMT, the shallower about 0530 h LMT. The deeper layer ceased its rapid descent near 180 fm (329 m), but continued downward at a slower rate eventually reaching a midday depth of 200 fm (366 m). The shallower layer reached 100 fm (183 m) prior to midday and by early afternoon it was down to 105 fm (192 m). As the deeper layer descended, parts of it broke up into scattering groups (to be discussed in a later section).
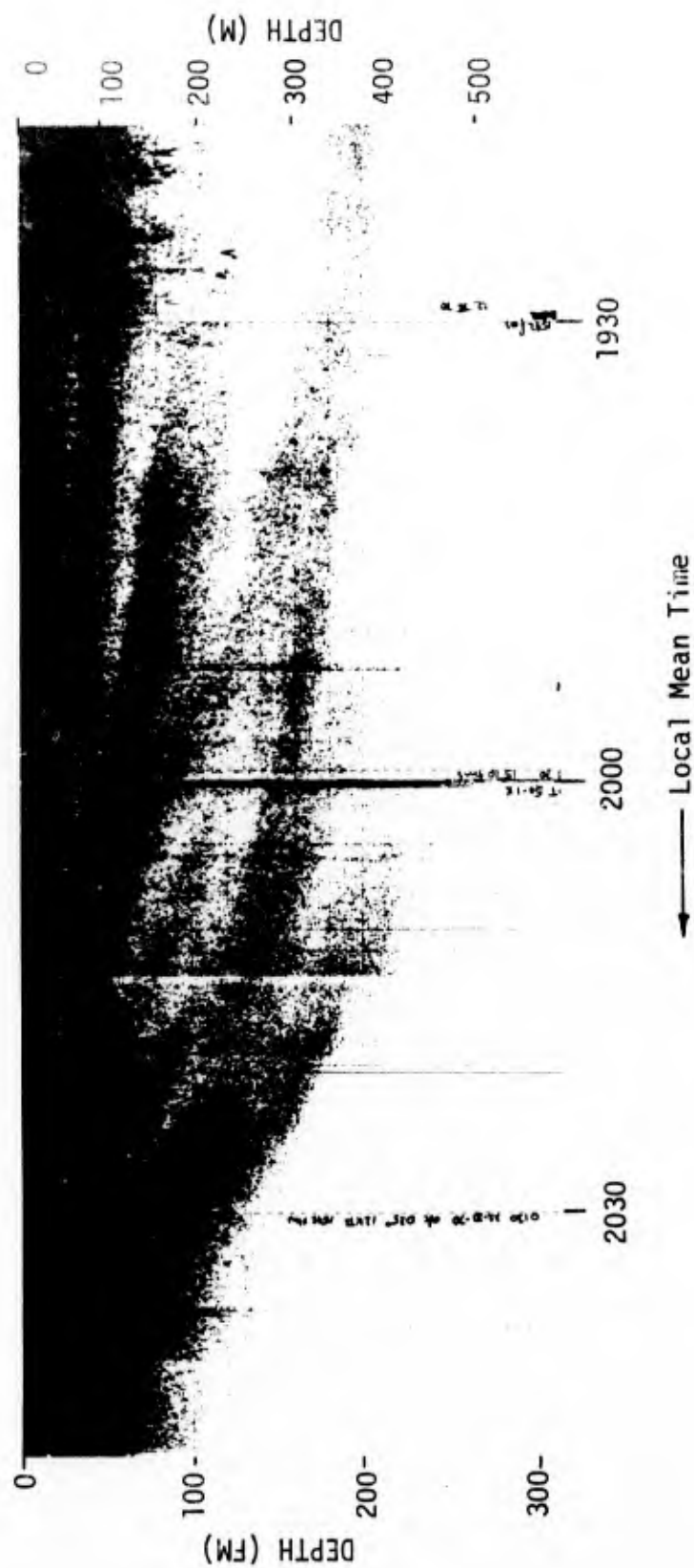
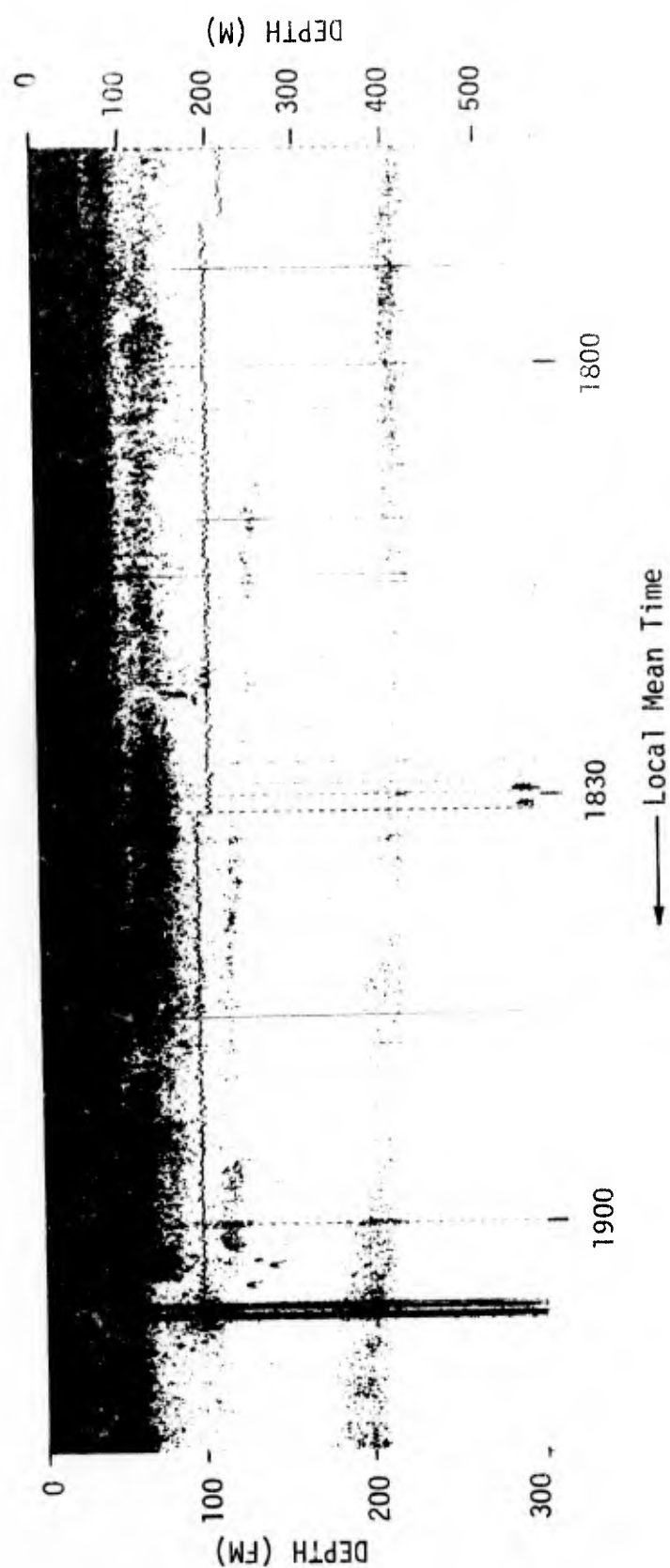Fig. 12 - Photograph of PDR trace showing an evening ascent.

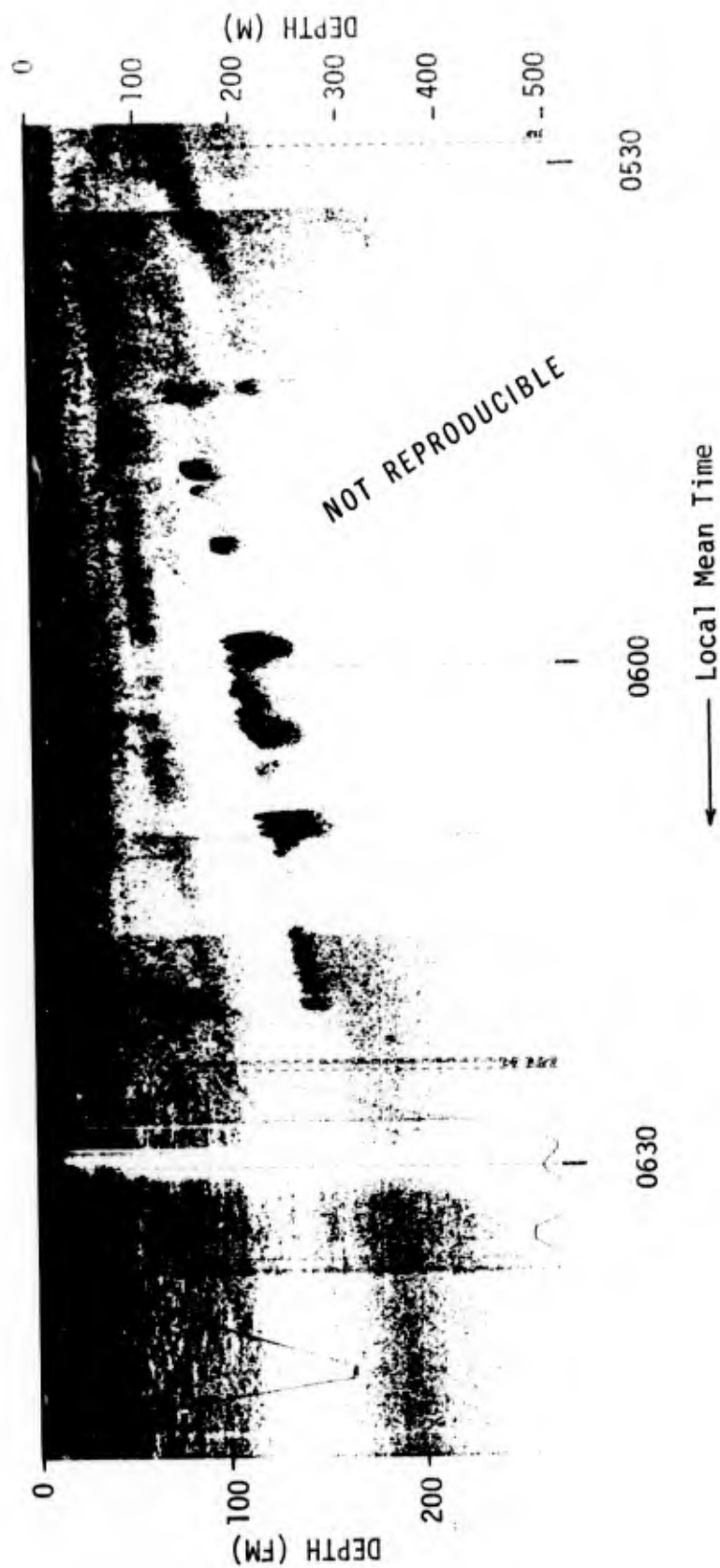Fig. 13 - Photograph of PDR trace showing an early portion of an evening ascent.

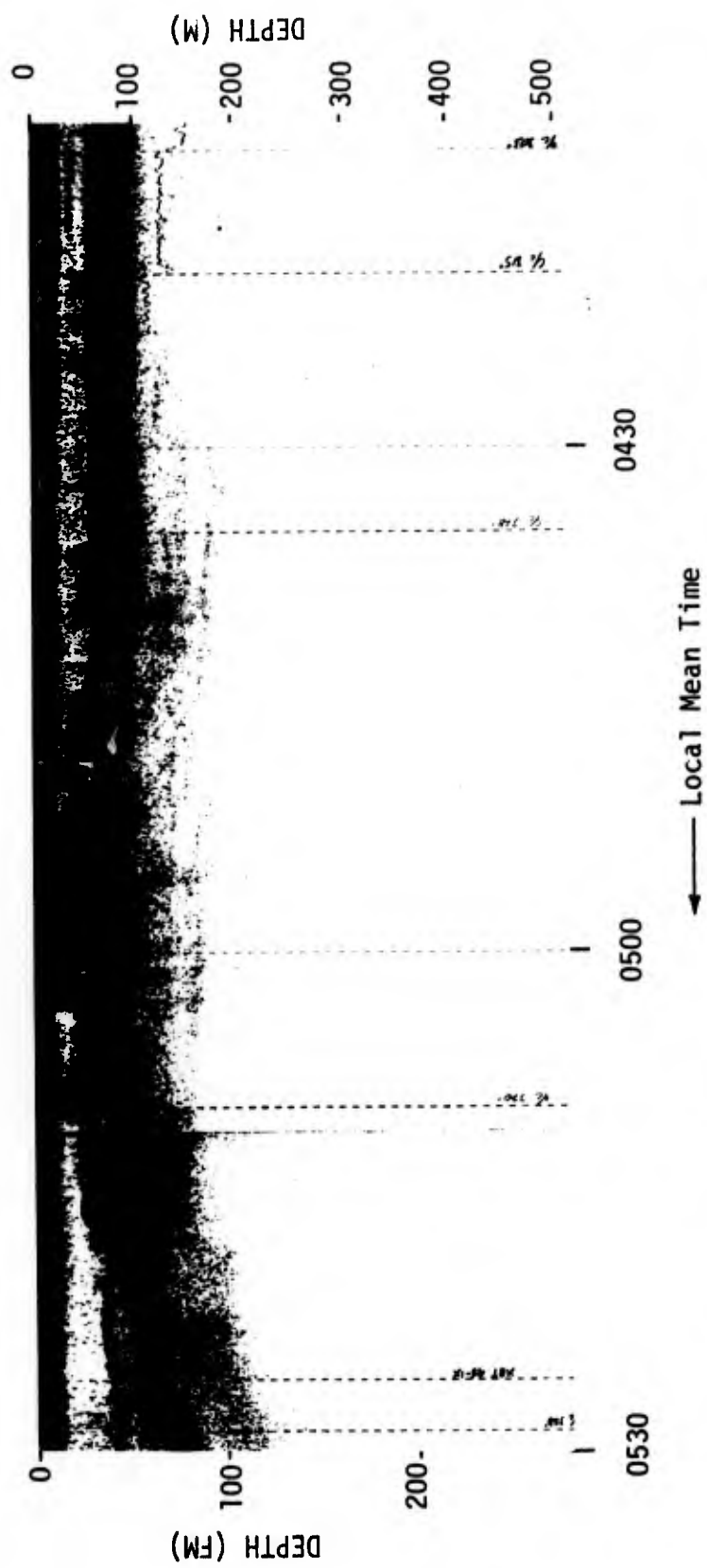Fig. 14 - Photograph of PDR trace showing a morning descent.

Fig. 15 - Photograph of PDR trace showing an early portion of a morning descent.

C. Dawn Rise

The organisms composing the DSL do not all remain at, or near, the surface throughout the night; many of them undergo a gradual settling.[32,33] The primary stimulant causing the diurnal vertical migration of the DSL appears to be light. There is the possibility, however, that organisms within the DSL are only following smaller organisms that are responding to the change in light intensity. It is probable that there is some optimum range of light intensity to which a member of the DSL responds positively (i.e., toward increasing light intensity). Upward migration is in response to a falling off of the light intensity reaching the layer. Then, as the sun sets and the light intensity falls below the optimum value, some components of the layers settle slowly primarily because of random movement of the organisms in the absence of any stimulus to respond to.[34] Toward dawn, they once again start their rise, seeking their optimum light value. Then, as the light intensity continues to increase, the organisms start an active descent due to negative stimulus (i.e., away from increasing light intensity).

Two examples of the dawn rise are presented: the first observed while maintaining station, the second while underway. Fig. 16 shows a definite rise of a layer which formed before 0530 h LMT, at a depth of 70 fm (128 m), and migrated upward between 0540 h LMT and 0600 h LMT. The dawn rise was also observed
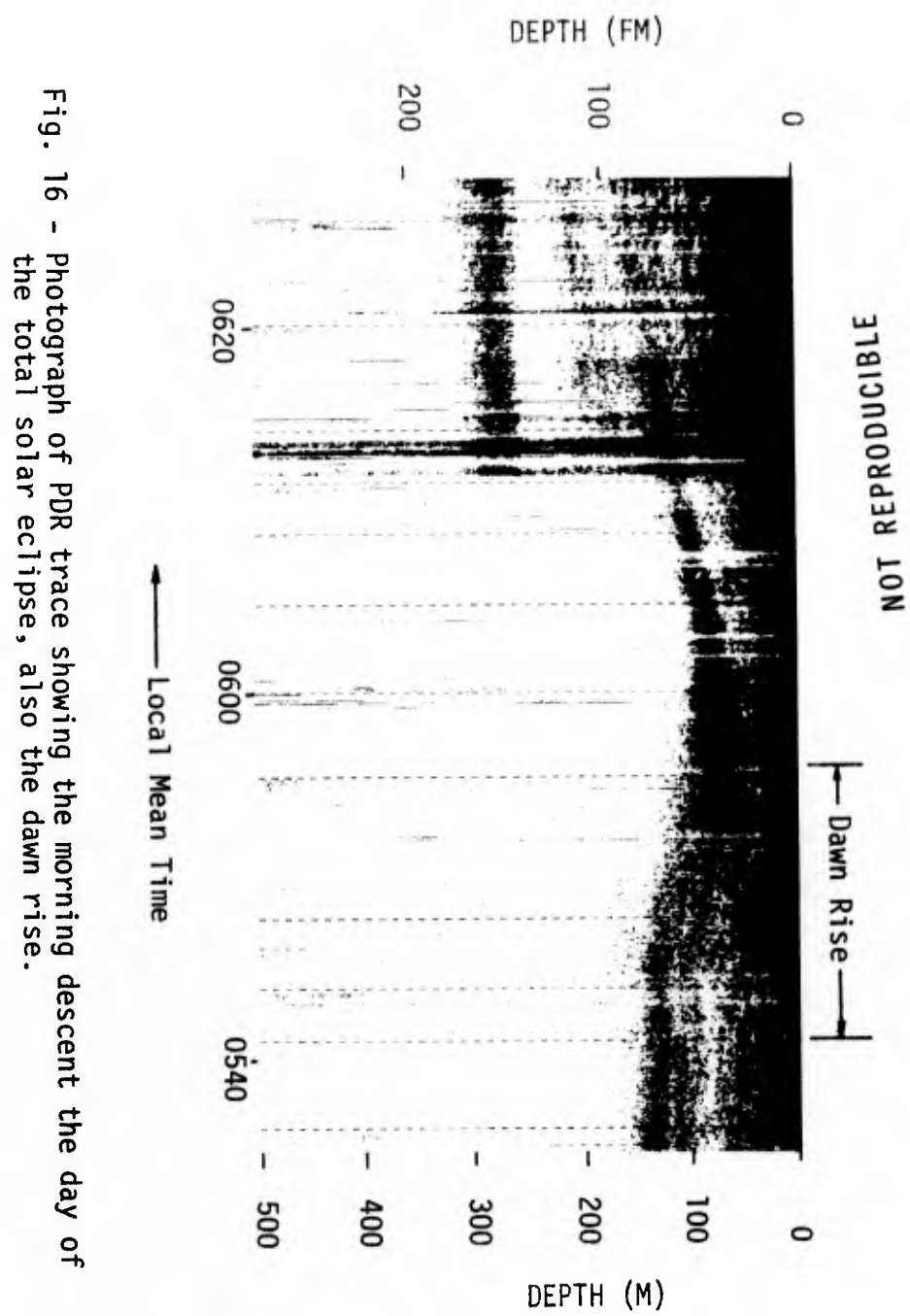
Fig. 16 - Photograph of PDR trace showing the morning descent the day of the total solar eclipse, also the dawn rise.

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on the following morning. A later cruise, in June 1970, produced
a good example of the dawn rise (See Fig. 15); a layer formed
prior to 0435 h LMT at a depth of 30 fm (55 m) and started its
dawn rise at about 0440 h LMT.

This phenomenon is apparently widespread as it has been
reported often in literature on the biological layering as inter-
preted from net tows.[34,35] No detailed acoustic reports, however,
have been written concerning the dawn rise. In at least one
instance the dawn rise was noted and discussed but not specifically
identified as such.[36]

D. Reaction to Solar Eclipse

Reported here are the results of observations of the DSL in
the Gulf of Mexico during a three-day period which included the
day of the total solar eclipse (TSE), March 7, 1970. The test site,
89° 31' W and 24° 01' N, was off the northern edge of Campeche
Bank in 1910 fm (3495 m) of water. This point was selected because
totality occurred at approximately local solar noon thus producing
a maximum observable effect of solar radiation and depth of the
DSL. On the day of the eclipse, occultation of the sun lasted for
2 h and 44 m (beginning at 1036 h LMT) and the total solar eclipse
lasted for 3 m and 5 s (beginning at 1156 h and 35 s LMT).

Several layers seemed to have responded to the TSE but the
most pronounced response occurred for the layer centered at

85-90 fm (156-165 m) (See Fig. 17). This layer migrated upward

about 4 fm (6 m) arriving at its shallowest depth about 23 minutes

after the TSE began.

Net tow experiments also seemed to indicate a vertical migra-

tion of the zooplankton in the upper 20 fm (37 m) in response to

the TSE.[37]

The migration of the DSL was quite complicated during the

afternoon of the eclipse, and it is not certain to what extent

the migration could be attributed to the eclipse. Several periods

of heavy overcast occurred that afternoon, as is evident in the

insolation curve given in Fig. 17. Much of the confused behavior

of the layering was probably attributable to this cloudiness. It

is clear that the DSL response to the TSE was small.

E. Response to Variations in Cloud Cover

There is some evidence to indicate that the deeper layers

of the DSL respond to cloud occultation of solar radiation. It

was noticed, on a number of occasions, that layers moved up when

the sun was occulted by a passing cloud. This vertical motion was

observed following the TSE (See Fig. 17) and on a subsequent cruise

a few months later (See Fig. 18). The light intensity at the

surface fell off some 80% while a DSL rose some 15 fm (23 m).

These measurements are the only insolation data known to have

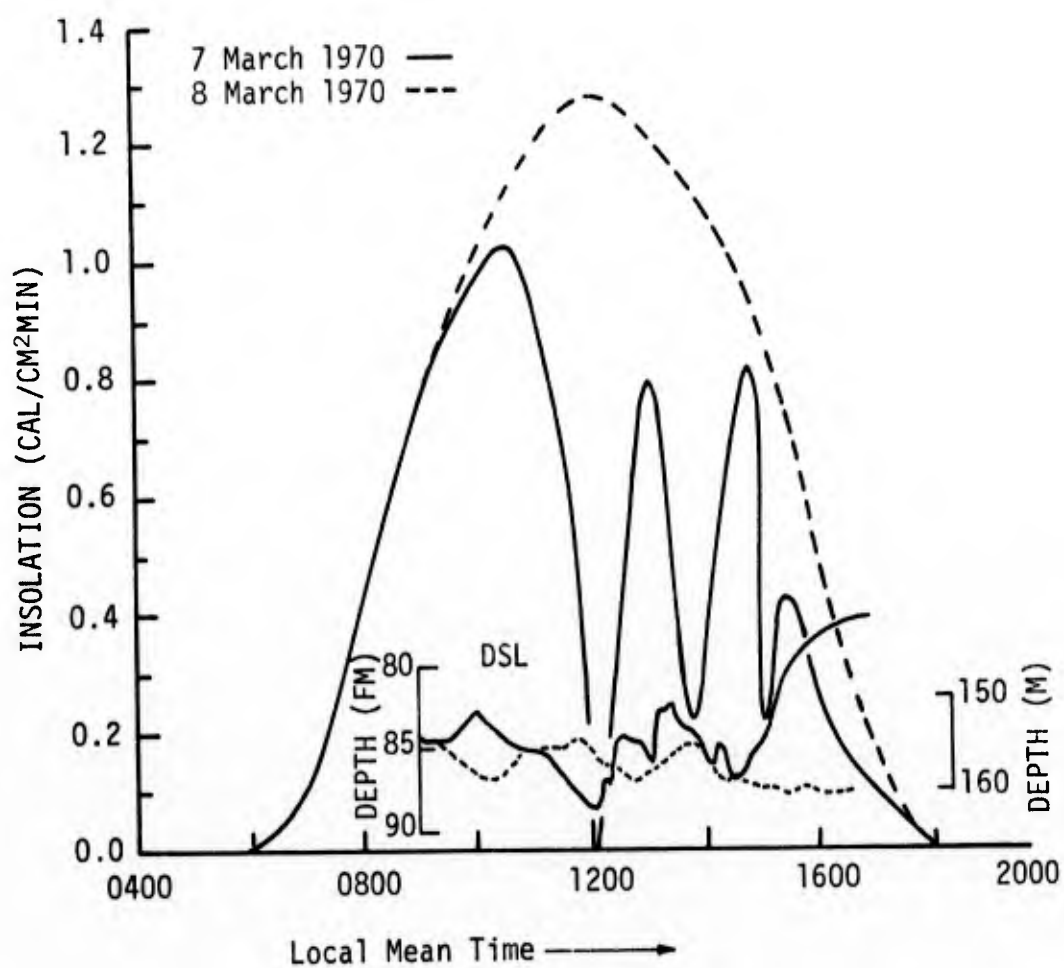been taken that can be directly correlated to DSL motion.
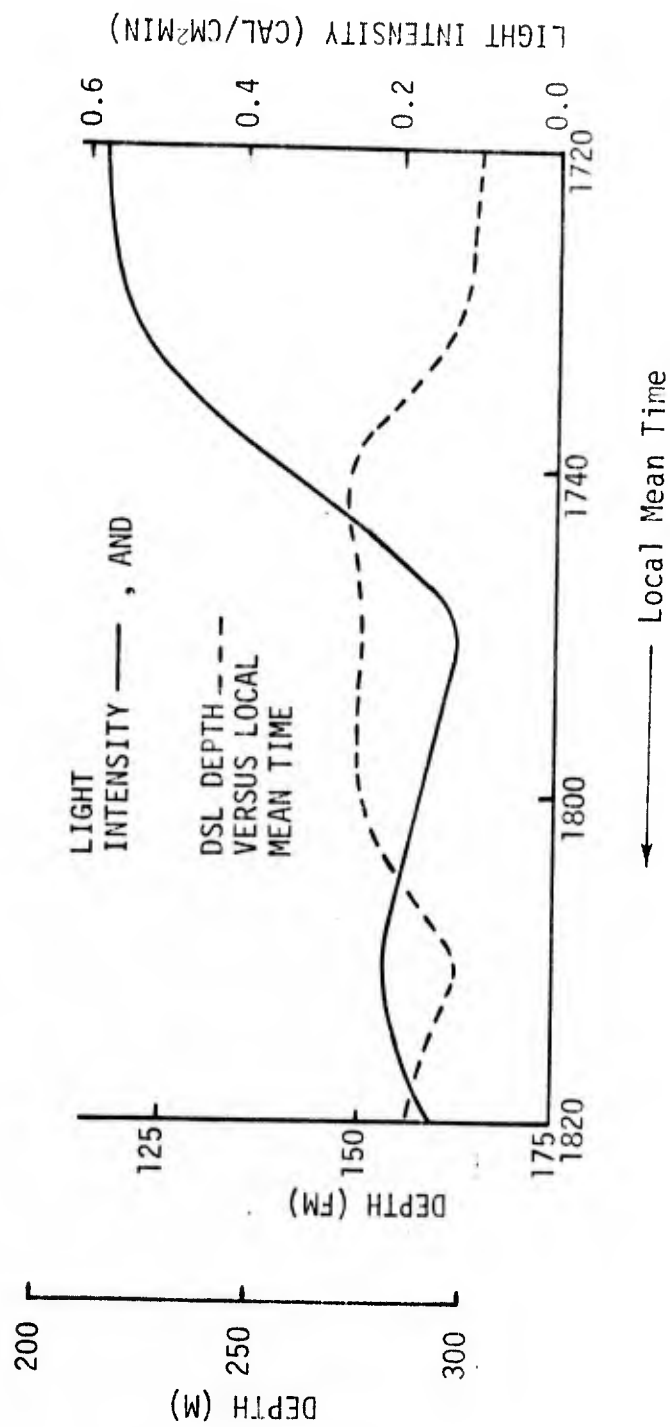
Fig. 17 - Insolation curve and DSL response.

Fig. 18 - Response of DSL to reduced insolation due to scattered clouds.

Measurements have been made, however, utilizing a submarine photo-meter off the coast of San Diego[38] and New England.[39]

F. Further Examples of the Character of the DSL

1. The DSL over the Continental Slope

This observation was complicated by a bottom multiple; also, this PDR trace was taken during the early portion of an evening rise. At the edge of the continental shelf, the DSL tends to conform to and rise with the bottom topography. Three layers were seen to exist: one at a depth of 60 fm (110 m) as well as two lower layers 3 and 6 fm (5 and 11 m) above the bottom, respectively (See Fig. 19). The lower layers appeared to remain a few fathoms above the bottom as the bottom profile changed; however, as the bottom dipped into a canyon the layers remained at stable depths across the canyon. As the bottom shoaled, on the far side of the canyon, the layers once again rose with the bottom.

The DSL were apparently prevented from being at their normal depth by the shoaling bottom; they appeared to prefer a shallower depth over that of drifting downhill to what would be their normal depth.

2. PDR Trace Compared for Ship Moving and Stationary

The character of the DSL, as obtained on PDR tracings, is strongly dependent upon whether the ship is moving or stationary.
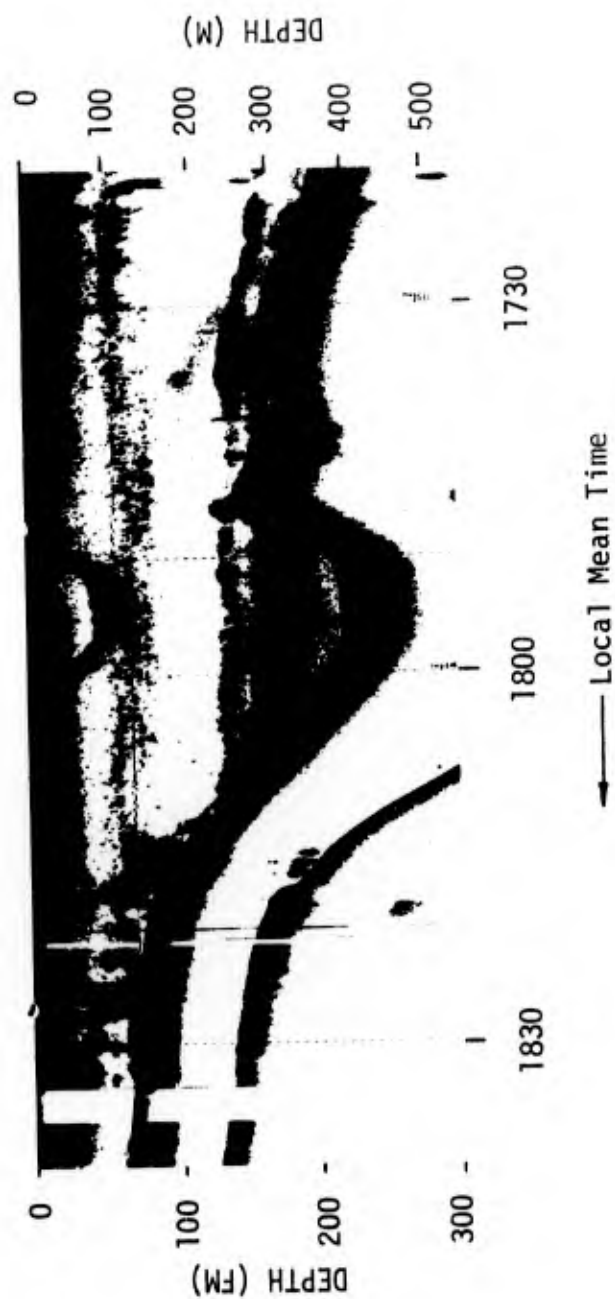
Fig. 19 - Photograph of PDR trace showing an observation of the DSL conforming to the bottom profile.

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Fig. 20 is a trace of the near surface DSL as a moving ship comes
to a stop. The character of the DSL, when the ship is underway,
is such that the trace of the DSL is composed of many small, some-
what irregular, tent (hyperbolic) shaped spots. As the ship
stops these spots become drawn out and the total number appears to
decrease. These drawn out spots are probably due to the presence
of individual organisms; the motion of the organisms through the
cone of sound emitted by the PDR produces the tent shaped trace.[40]

3. Scattering Groups

Quite often scattering groups are seen on the PDR trace ob-
tained on crossings of the continental slope (See Fig. 21) and in
the open sea (See Fig. 22). These groupings probably consist
of schools of organisms such as fish, squid, etc. Another possibil-
ity is that they are composed of organisms grouped together because
of physiological reasons, e.g., the particular volume of water they
are occupying is the most comfortable or advantageous to their
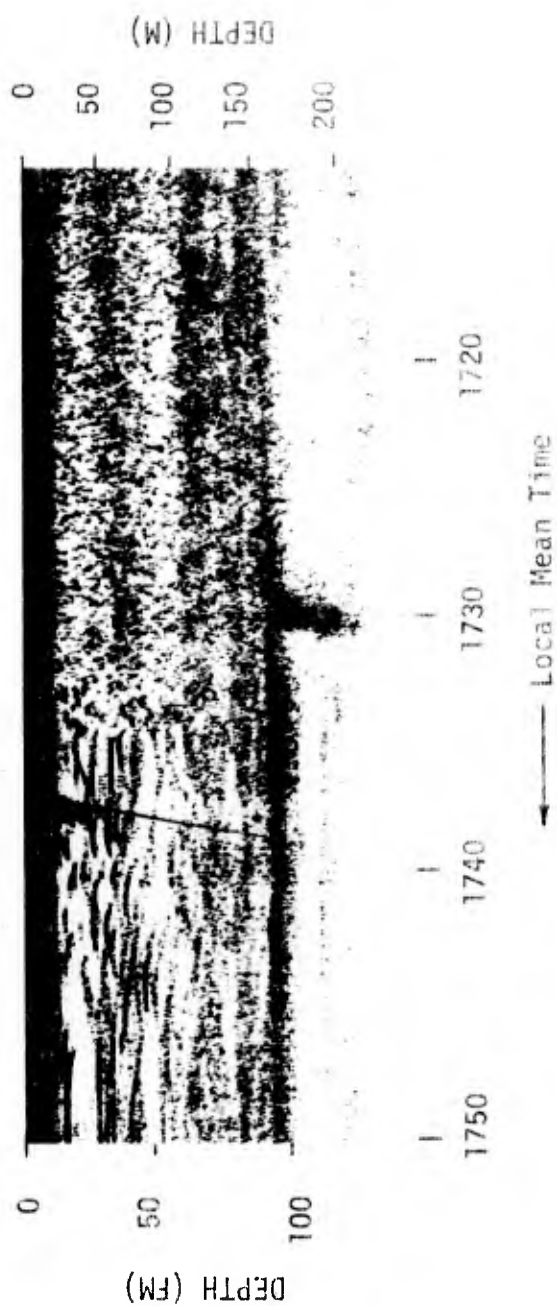existence.

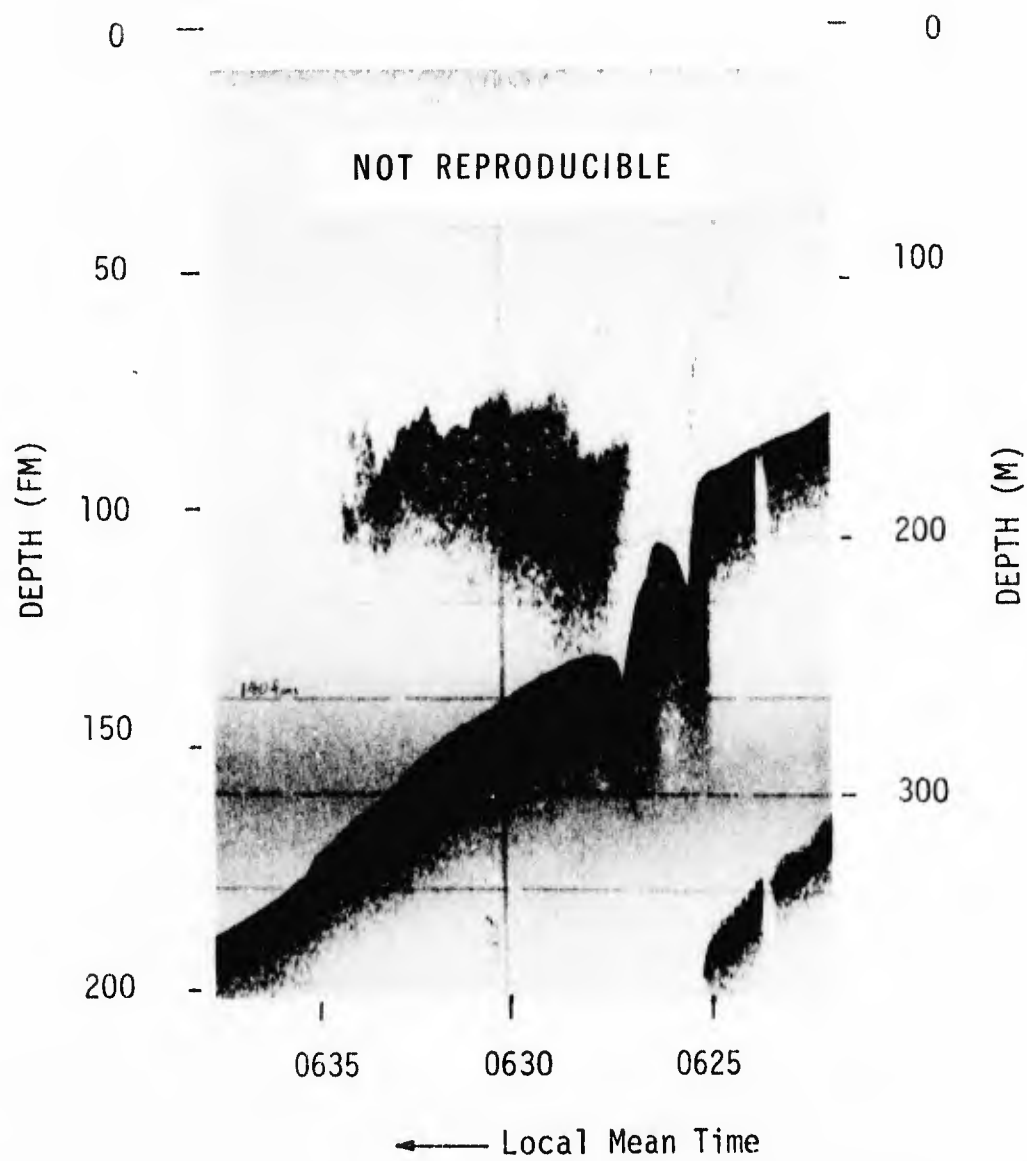Fig. 20 - Photograph of PDR trace showing DSL while ship is stationary and underway.

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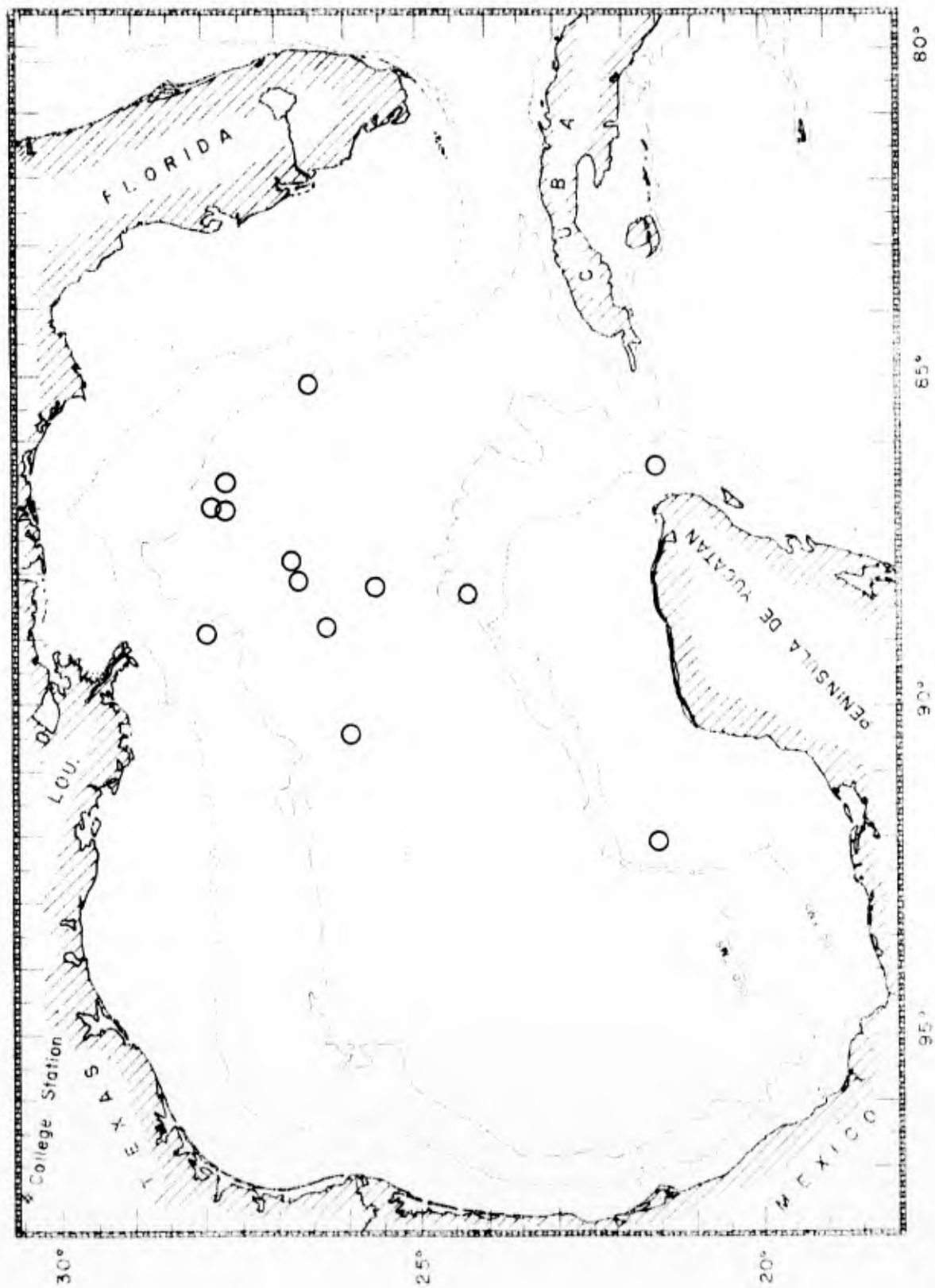Fig. 21 - Photograph of PDR trace showing an
example of scattering groups.

Fig. 22 - Location of observed scattering groups.

IV. SUMMARY

Observations of the DSL in the Gulf of Mexico over an extended period of time have produced the following results:

- documentation of the existence of widespread layering in the Gulf, including multiple layering in most cases, at depths to 260 fm (476 m);

- average descent rate of 1.3 fm/min (2.3 m/min), average ascent rate of 1.8 fm/min (3.3 m/min), and maximum rates of 3.4 and 5.9 fm/min (6.1 and 10.8 m/min), respectively--a slow descent follows the morning rapid descent, and, conversely, a slow ascent preceeds the evening rise;

- the available data tends to indicate that there is little or no correlation between the DSL and various physical parameters, either on a regional basis or localized;

- the dawn rise was seen and noted on a number of occasions;

- a response of the DSL to a total solar eclipse is reported--there is some question, however, as to whether this response was due to the solar eclipse or to the scattered clouds present at the time of the eclipse;

- data were obtained which tend to indicate that the deeper layers of the DSL respond to occultation of the sun by clouds;

- the scattering layers, as recorded by the PDR, do not always consist of what could be called layers--often the tracings

are of a discrete nature, and most likely represent single
organisms, or aggregates of organisms; and

- one observation of the DSL in the vicinity of the shelf edge
indicated that it conformed to the local bottom topography
in this region.

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